This is a reproduction of a library book that was digitized by Google as part of an ongoing effort to preserve the information in books and make it universally accessible.

Google™ books

https://books.google.com



UC-NRLF
B 3 123 717

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

US Bureau of Naval Personnel
Ed Sep



OL. 1

IRE CONTROL TECHNICIAN
1 & CHIEF

NAVY TRAINING COURSES

NAVPERS 10176

Digitized by Google

Digitized by Google

FIRE CONTROL TECHNICIAN 1 & C

VOL. 1

Prepared by

BUREAU OF NAVAL PERSONNEL

U.S.



NAVY TRAINING COURSES

NAVPERS 10176

DOCUMENTS DEPARTMENT
JUN 7 1959
LIBRARY
CALIFORNIA

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1953

Digitized by Google



Digitized by Google

VF520
U5
v. 1

PREFACE

This book is written as an aid in preparing Fire Control Technicians 2 and 1 for promotion to the rates of Fire Control Technician 1 and Chief Fire Control Technician.

Because of the extensive qualifications required for Fire Control Technician 1 and Chief Fire Control Technician (see appendix III), it was found advisable to divide the study material into several volumes. This book, designated Volume I, covers the general aspects of surface gun fire control, torpedo fire control, underwater fire control, optical rangefinders, and basic mechanical mechanisms. The other volume or volumes will be concerned primarily with anti-aircraft fire control, advanced electronics, and radar.

Since men in the fire control Technician rates are becoming more and more a group of system or equipment experts, it is the present purpose to include more of the basic material which is applicable to all types of gear, rather than to emphasize a single system. Wherever specific gear *is* described in the text, it is done mainly for the purpose of applying certain basic fundamentals or to show the applications of abstract materials.

As one of the NAVY TRAINING COURSES, this book represents the joint endeavor of the Training Publications Section in the Bureau of Naval Personnel and those naval establishments especially cognizant of the technical aspects of fire control. Special credit is given to the Fire Control Technician School, Class B, Washington D. C., for assisting in the technical review of the text.

188

Digitized by Google

READING LIST

NAVY TRAINING COURSES

Electricity, NavPers 10622–B.
Fire Controlman 3, Vol. 2, NavPers 10164–A.
Fire Controlman 2, Vol. 1, NavPers 10035–A.
Fire Controlman 2, Vol. 2, NavPers 10035–B.
Fire Controlman 2, Vol. 3, NavPers 10035–C.
Electricity for FC and FC Technicians, Vol. 1, NavPers 10170.
Electricity for FC and FC Technicians, Vol. 2, NavPers 10171.
Advanced Mathematics, NavPers 10071.

OTHER PUBLICATIONS

BuShips Manual, Chapter 71.
BuOrd Manual 1943 (With changes 1–10), Chapters 1A, 1B, 1F, 2, 3, 11.
Naval Ordnance and Gunnery (chapters 24, 25, 28, 32, 33), NavPers 16116–B.
Radar Electronic Fundamentals, NavShips 900016.
Radar System Fundamentals, NavShips 900017.
Ordnance Pamphlets, 1303, 1140, 1140A.

Digitized by Google

CONTENTS

Chapter	*Page*
1. The FC division	1
2. Ballistics and tables	17
3. Mechanical multipliers	43
4. Component and vector solvers	63
5. Mechanical integrators	93
6. Fire control gyroscopes	113
7. Linkage computing mechanisms	137
8. Electro-mechanical servo mechanisms	173
9. Solving wind corrections	199
10. The relative motion problem	219
11. Deck and trunnion tilt	251
12. The gun orders	295
13. Generated rates	317
14. Rangefinders	341
15. Torpedo fire control	375
16. Underwater fire control	405
Appendix	
I. Answers to quizzes	441
II. Surface fire control symbols	449
III. FT qualifications	453
IV. Trigonometric table	461
Index	463

Digitized by Google

Digitized by Google

FIRE CONTROL TECHNICIAN 1 & C

VOL. 1

Digitized by Google

Digitized by Google

CHAPTER 1

THE FIRE CONTROL DIVISION

During your fire control career thus far, you've been working with some of the most complicated machines ever devised. You've performed operators' adjustments and tests on computers and rangekeepers, disassembled and overhauled receiver-regulators, and performed most of the routine maintenance jobs on your ship's fire control equipment. You've fired in earnest or for practice and learned current gunnery doctrine, battery alinement, and basic electronics.

Those stripes on your arm show how far up you've come in your rating as Fire Control Technician. They show you have learned your job well and are willing to assume the responsibilities which come with promotion. They mark you as a specialist in a growing field.

You are now preparing to enter on a new phase of your career. While learning more about fire control, you must also learn to teach and to supervise others. The performance of your men and the training they receive will be your responsibility. As a leading first-class or chief, it will be your duty to see that orders are carried out and jobs completed. Of course, the highly skilled jobs such as balancing the gyro of a stable element, tuning a fire control radar, or calculating roller path corrections will fall to you; but mainly you'll be directing and observing the work of your men. That'll be your primary job—to SUPERVISE.

Digitized by Google

It is now time for you to think more of developing the capacity for independent thought and action. In your new rate you will become responsible to the fire control division officer for the efficiency of the ship's fire control equipment. Instead of your asking the chief to explain an operating procedure, or to locate an elusive equipment trouble, you will probably be the chief and the men will be coming to you with similar problems. You'll have to know your business. Nothing destroys the morale of men so much as the suspicion that their superiors do not know their jobs.

You've been told dozens of times that a Petty Officer is first of all a leader and, secondly, a specialist. The two are not divorced; you are a leader in your specialty too, or you would not be where you are. You are responsible for attaining a high degree of proficiency in all the general qualifications of Petty Officers, as well as in all the qualifications of Fire Control Technicians of your rate.

As a Petty Officer, you have certain military duties; and, as a specialist, you have certain technical duties. This book is not concerned with your military duties. They are explained in the Navy Training Course, *General Training Course for Petty Officers, Part 1*, NavPers 10602–A and in other pertinent Navy publications. Wherever your duties are discussed in following chapters, the reference is to your specialist duties.

PURPOSE OF THIS BOOK

It's the purpose of this book to explain the fundamentals of what you should know. But, remember, this book contains only the fundamentals. No single book could cover all the ground, and certainly no number of books could ever substitute adequately for actual experience. Almost everything about a fire control system is intricate. The skills you have developed came not only from books but from actual manipulations of tools, test instruments, and all the gear with which you work. Your skills are in your nerves and muscles.

Nevertheless, books help one understand a piece of gear or an operation, and they organize and explain. Unorgan-

Digitized by Google

ized knowledge may often be useful, but organized knowledge is clearly essential to success, no matter where you work. This book is meant, in part, to help you organize what you already know; in addition, it will tell you a few things you don't know, as it has been necessary to include a discussion of the technical subjects needed to keep abreast of fire control developments. Most important, this book is also meant to help you organize supervision. A teacher cannot teach successfully unless he first organizes what he intends to teach.

There's an old saying: "If the learner hasn't learned, the teacher hasn't taught."

If the strikers and rates under your supervision aren't learning, the fault very probably lies with you. You haven't taught them.

To sum it up, as a specialist you have three different types of jobs: (1) You have certain duties at general quarters when you take your battle station; (2) you have routine maintenance duties, consisting of care and upkeep of all gear with which you work; (3) you have supervisory and training duties, which overlap your general quarters and routine maintenance duties. The purpose of this book is to outline these three types of jobs for you.

This training course is meant to be useful for three rates:

1. It is a reference library to refresh the memory of the Chief Fire Control Technician.
2. It is an outline of duties for the Chief Fire Control Technician and for the Fire Control Technician first class.
3. It is a course of study for the Fire Control Technician 2 who wants to become a Fire Control Technician 1, and for the Fire Control Technician 1 who wants to become a Chief.

This course is not meant to take the place of ordnance pamphlets, operational bulletins, and other detailed technical publications. You will consult such publications when you have need for the far more detailed information and procedures contained in them. A list of the types of these

Digitized by Google

specialized publications appears in another chapter, together with notes on the kind of information they contain. Consult the fire control officer when you need such information. He has, or can get, any publication you want. It won't hurt you to have more knowledge than your immediate duties call for, and a very important part of your knowledge is knowing where you can find the answers.

THE ORGANIZATION AS A WHOLE

In fighting ships, Fire Control Technicians are members of the gunnery department, and they are under the immediate supervision of the fire control officer. The chief fire control officer is the gunnery officer. The gunnery department is part of the standard ship organization, the form of which is shown in figure 1–1. In small ships the duties of the gunnery officer and first lieutenant may be combined. A study of the chart will show you exactly where you fit in. In actual practice, the standard ship organization is adapted to the type of ship concerned; you may find that your organization varies slightly from standard.

The standard ship organization vests in the commanding officer the responsibility for the performance of his command. The commanding officer, in turn, delegates duties to his executive officer and the various officers who administer the departments.

Study this standard ship organization chart. Your commanding officer uses this chart as a guide in assigning the ship's personnel for the most efficient administration and maintenance of his ship. In turn, the gunnery officer will assign his men to the battle bill from the personnel shown on the standard ship's organization.

As a Fire Control Technician 2 you looked at the battle bill to learn your general quarters station. But as a First or Chief, you will have to know your ship's complete battle bill. A thorough knowledge of your ship's battle organization is necessary if you are to relieve your division officer in an emergency.

Digitized by Google

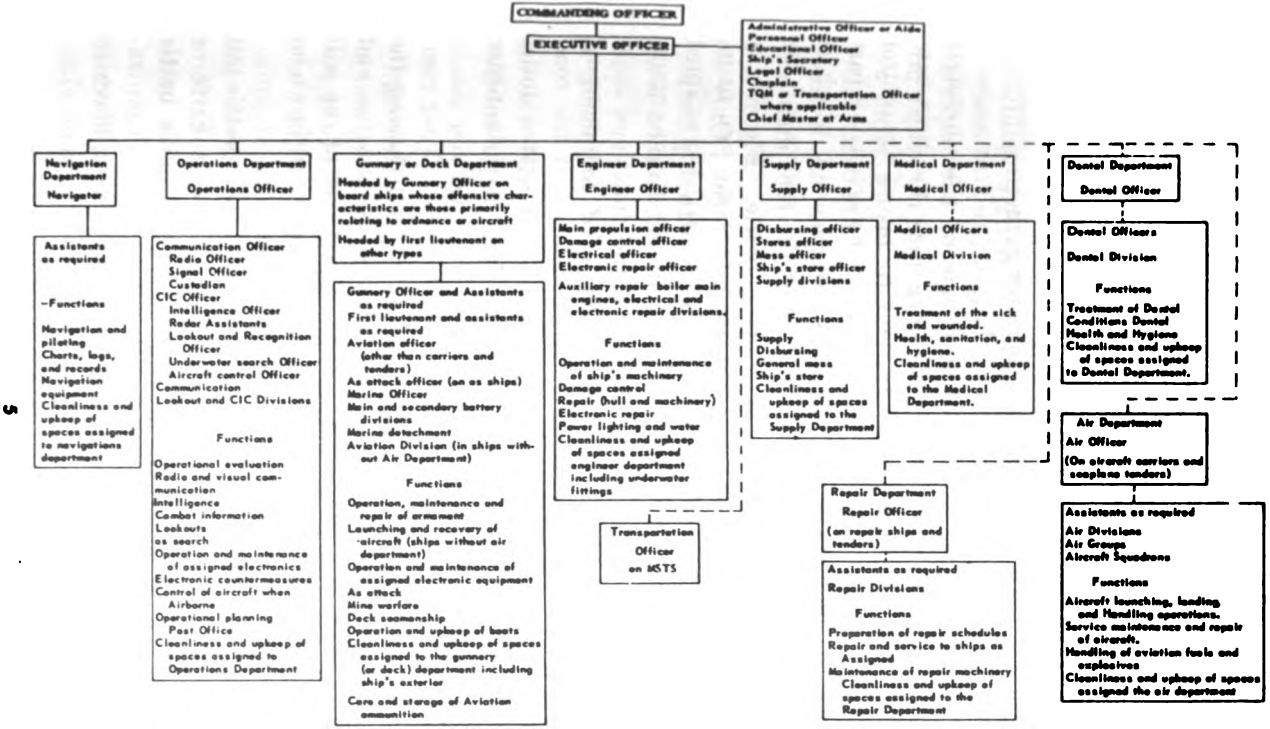


Figure 1–1.—Chart showing the gunnery department within the standard ship organization.

Digitized by Google

THE BATTLE BILL

In order that a ship's armament and fire control can be used to perform its primary function—that of destroying the enemy—an efficient organization of personnel and material, and excellent interior communication must be provided. On practically all ship types, and particularly on the larger ones, the fire control stations are widely separated; yet each is dependent upon the others for gathering information, computing data to be used by the guns, and transmitting that data to the guns. Therefore, one of the important phases of shipboard gunnery is to organize the ship's personnel and material effectively, and to insure rapid and accurate communication and application of fire control data.

In all U. S. Navy combatant ships a BATTLE BILL is drawn up for the guidance and coordination of the four main subdivisions of ship organization during battle. Figure 1–2 shows such a battle bill in diagrammatic form. Only the fire control subdivision (representative of battleship installations) is fully outlined here. Each main subdivision is administered by a separate organization, and functions under the commanding officer through a chain of command, as illustrated for fire control.

The purpose of this discussion is to deal with the fire control organization. Nevertheless, all four major subdivisions are closely related in fighting the ship and you should know how they are coordinated.

One of your duties is to study the battle bill thoroughly. This bill includes the organization plan of the ship, and all subdivisions are explained in detail. The duties of the personnel in each of the fire control stations are outlined, and the relationship of each station to the entire battle organization is explained. Study the battle bill with great care before assuming that flaws exist. Often the reasons for a particular plan may not be obvious in daily drills under relatively peaceful circumstances.

The organization shown in figure 1–2 is an example which varies from ship to ship, even in ships of the same class.

Digitized by Google

¼ bound	
½ cloth	
Rebind	
Recase	
Correction	
Chg lettering	
Blue	Brown
Red	Maroon
Purple	Orange
Refolds	
Double spreads	
Narrow inner margins	

VE

covers

front covers

back covers

covers except first and ast of volume

ads

ads in first number

ads in last number

ads incl those paged in

IAL INSTRUCTIONS



Digitized by Google

No.....

..	Prep.....h.....m.....	Fwd.....h.....	
..	Sew.....h.....m.....	Fin.....h.....	
...	Total.....h.....m.....	Total.....h.....	

REPORT EXTRAS



indery Slip–Serials 21–100*m*-2,'58(2150s4)4119A

Digitized by Google

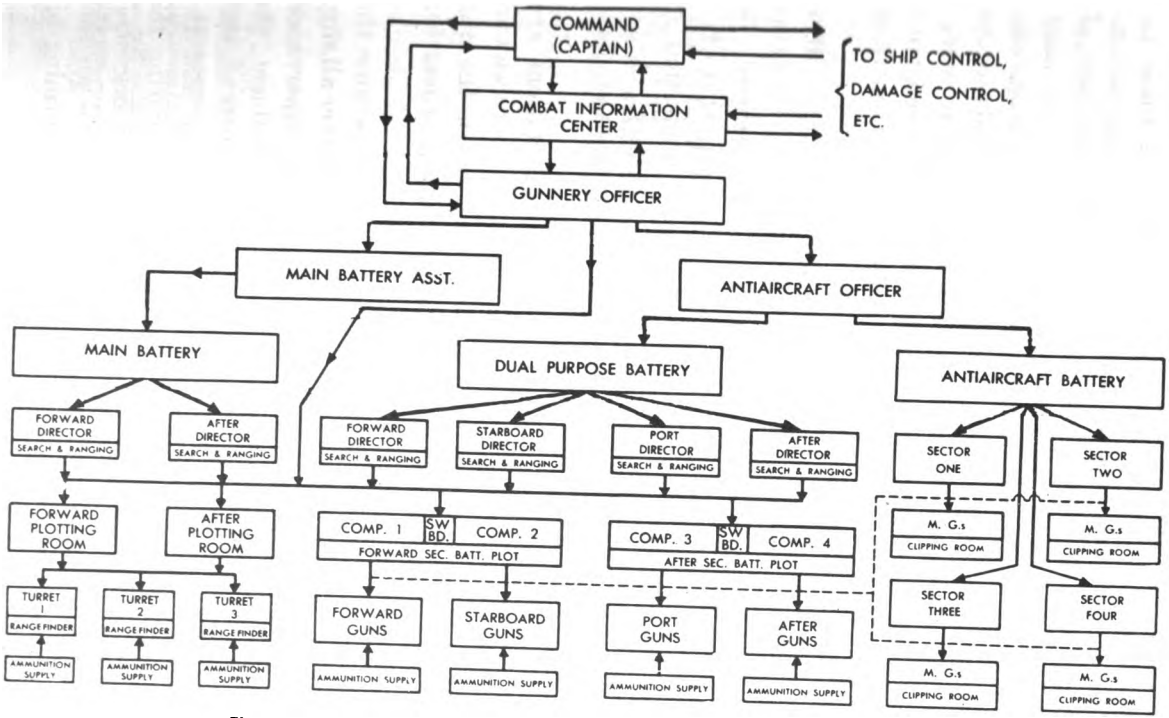


Figure 1–2.—A portion of a battle bill showing the fire control organization.

Digitized by Google

The arrangement varies to fit the requirements of the individual ship. Naturally, however, every effort is made to standardize the organization for each type of ship; for example, a battleship's battle bill closely follows the typical chart shown. It is desirable that the organizations for other ship classes closely parallel this master pattern to the extent that it is possible. It enables all members of the naval service to be generally familiar with a typical setup; thus, an interchange of personnel does not present a major training problem, and new hands may be worked into the existing organization aboard any ship with ease.

Thus, though the organization for various ships may differ in detail, the one shown in figure 1–2 covers the essential features common to all combatant types. For example, a heavy cruiser organization is almost identical with that of a battleship. Also, a destroyer main battery organization is similar to that of a battleship's secondary battery. Antiaircraft organizations for practically all ship types are patterned after the one shown in figure 1–2.

In figure 1–2, the various subdivisions and stations are connected by lines which show both the CHAIN OF COMMAND and the FLOW OF INFORMATION. Opposed arrows on the line indicate the transmission of data and resulting orders for proper use of the information.

Notice that all lines originate from command because the captain, from his battle station, exercises control over all ship activities. In particular, he is responsible for the supervision of his ship's course and speed, the use of armament, the preservation of watertight integrity, the rectification of casualties to personnel and matériel, and the receipt and dissemination of information. The task of coordinating the many activities to obtain a smoothly functioning organization is tremendous. It is therefore necessary that another agency be available to assist the captain in performing his functions.

Digitized by Google

COMBAT INFORMATION CENTER

The function of the combat information center (CIC) is to assist command in planning a correct course of action, and to assist command and fire control in the execution of that plan. The CIC is, briefly, an agency for the collection, evaluation, and distribution of combat information, and for facilitating the use of that information. It is not something strange and complex, nor is it merely another plotting room under a new name. It clarifies and simplifies the work of command in preparing for or carrying out combat operations.

Rapid progress in facilitating an early solution of the fire control problem was made possible by improvements in equipment and methods, and by developments in techniques for obtaining accurate target information before the target could be seen. The coordination of intricate gunnery problems with considerations of tactics, ship damage, and exterior communications is the commanding officer's primary

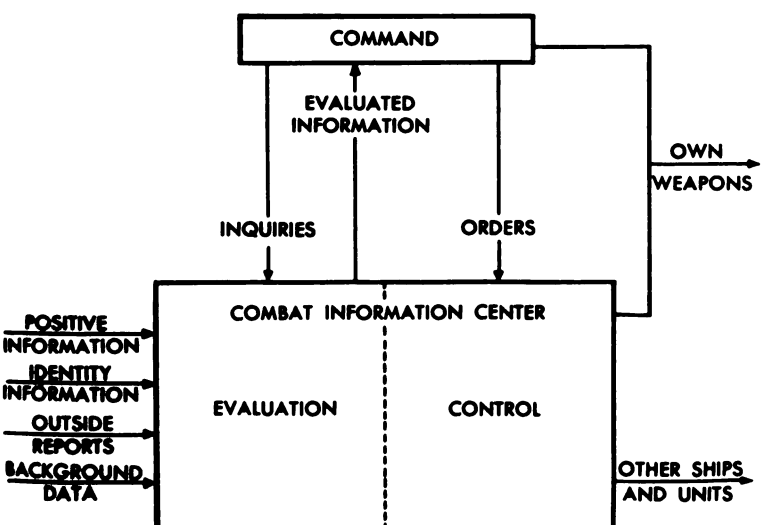


Figure 1–3.—Combat information center.

Digitized by Google

function during combat. During an engagement the captain is besieged with a vast number of informational items, each of which must be weighed individually to determine whether it should be used, discarded, or mentally filed for future reference. The CIC assists the captain in carrying out his responsibilities by filtering and evaluating nearly all incoming information. The captain is given the required data as he needs it, and thus is free to concentrate on his decisions and carry the burden of command. CIC may also include an organization to which the captain delegates secondary decisions and control duties as occasions may require.

The CIC may be arbitrarily divided into two sections, EVALUATION and CONTROL, whose functions are illustrated in figure 1–3. The control activity, with respect to own weapons, is of primary interest in this discussion. With its facilities for detecting, tracking, and communicating CIC can be of great assistance to fire control, particularly when visual observation is poor. Some of the functions it can perform are:

1. Designate or suggest suitable targets.
2. Coach gun control on targets.
3. Provide an initial solution for computing mechanisms in plot.
4. Warn automatic weapons of approach of hostile planes and torpedo boats.
5. Aid in radar spotting.
6. Inform fire control personnel of the presence of friendly forces in the vicinity.
7. Relay to fire control personnel orders and information of direct interest from higher authority.
8. Assist in liaison with shore fire control parties or other fire control establishment located outside the ship.

THE CHIEF FIRE CONTROL OFFICER

The fire control organization functions under the GUNNERY OFFICER and directly under the SENIOR FIRE CONTROL OFFICER. On small ships they may be one and the same.

Digitized by Google

The fire control organization has three principal subdivisions: main battery, secondary battery, and AA battery. Although the gunnery officer exercises command over each subdivision, he normally performs only supervisory functions in connection with all but the main battery, which he controls directly. During battle, the gunnery officer is in immediate communication with the captain and with the officers in charge of the main battery subdivisions such as plotting, turret, and spotting stations, as well as with those officers in control of the secondary and AA batteries.

In general, the broad duties of the gunnery officer may be outlined as follows:

1. He informs the captain as to the general gunnery situation and the practicability of opening fire.
2. Prior to opening fire with the main battery he designates targets at which to fire, the fire distribution to be employed, the gun directors to be used, and the firing method of battery control to be employed.
3. He keeps in touch with the various armament subdivisions and their activities. He is advised regarding casualties, and directs such redistribution of personnel as may be necessary to maintain the maximum efficiency of the armament as a whole.

As noted above, one of the gunnery officer's chief functions is target designation for all the armament subdivisions, which is made in accordance with the captain's instructions. In the case of a main battery target, it is probable that there will be a specific assignment for all ships of the battle line, in the form of a fire-distribution signal. Thus the designation of a main battery target may actually be originated from without the ship, and the order transmitted by the captain to the gunnery officer. If more than one target is assigned, the captain specifies the manner of dividing fire. Targets for secondary and AA batteries are less likely to be designated from without the ship, and these decisions may be made by the captain. On the other hand, targets may be selected and fire opened by officers controlling the respective

Digitized by Google

batteries, without direct orders to do so, if this is in accordance with standard instructions.

ANTIAIRCRAFT BATTERY CONTROL

Since the defense against air attack may involve more than one subdivision of the ship's armament, and since the presence of potential air attack may not be realized because of the gunnery officer's immediate preoccupation with surface targets, major vessels detail an officer as ANTIAIRCRAFT OFFICER or AIR-DEFENSE OFFICER. His primary function is to coordinate the ship's defense against aircraft in order that the gunnery officer may devote his entire thought and energies to the use of the ship's offensive armament against the primary objective. The air-defense officer may be delegated to open fire on hostile planes on his own initiative, without direct orders from the captain, either in accordance with standard doctrine or upon the captain's standing orders.

The air-defense officer may not necessarily control the firing groups directly, but may act in a supervisory capacity over the various gun groups through their respective control officers. He may designate targets, cause a shift in the guns firing at certain planes, and generally direct the ship's AA defenses. The antiaircraft officer is usually in direct communication with the captain and the CIC liaison officer, as well as with the sector and group control officers of the antiaircraft battery. In ships with a dual-purpose main battery, the gunnery officer himself may be the antiaircraft officer, or he may act as CIC liaison officer.

BATTERY CONTROL

Each main subdivision of any ship's armament (main battery, secondary battery, AA battery, torpedo battery, antisubmarine battery) is controlled by a BATTERY CONTROL OFFICER assigned to it.

Each control officer is directly responsible to and in communication with the captain, the gunnery officer, and, when

Digitized by Google

appropriate, with the antiaircraft officer. In addition, each battery may be subdivided into groups containing two or more gun mounts (or turrets). Such a group may be controlled by an officer designated as a GROUP CONTROL OFFICER. Such subdivision of a battery is justified because it affords greater flexibility, particularly in case of casualties or when divided battery control is necessary.

In the case of antiaircraft guns, each battery group is usually given direct responsibility for one sector of the area surrounding the ship, in which sector it has responsibility for protecting the ship against surprise attack. There are usually four sectors, each covering an arc of 110°, thus allowing a 20-degree overlap of sector boundaries as shown in figure 1–4. Sector control officers may be delegated authority over groups of more than one battery at such times as those groups are assigned the same sector.

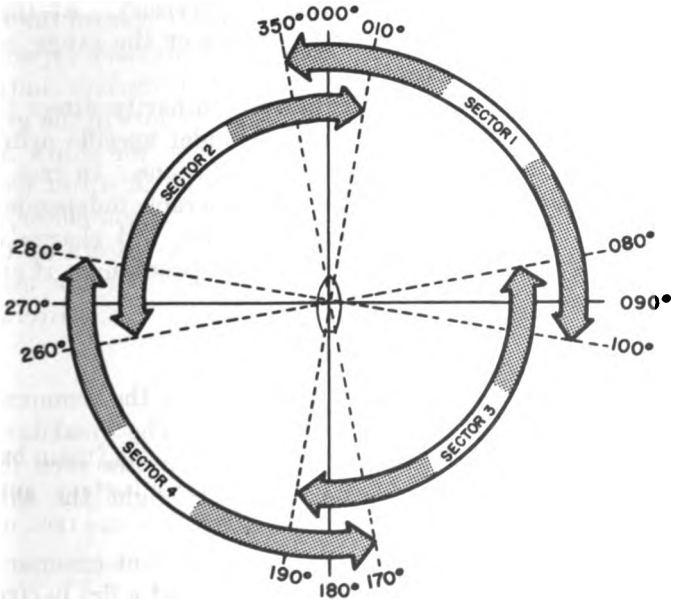


Figure 1–4.—Sector assignment of AA battery.

Digitized by Google

In main and dual-purpose batteries, group control officers will normally be associated with individual directors, and they are most frequently stationed at the directors. Group control officers of other batteries may in some cases be similarly stationed, if appropriate to the equipment installed on the ship.

TURRET OFFICER AND MOUNT CAPTAIN

As a final step in the chain of command, each turret or gun mount is under the direct, personal, and immediate control of an officer or petty officer at the mount. In the turrets, this control is usually exercised by a TURRET OFFICER, assisted by a turret captain (a petty officer). Commissioned officers are rarely stationed in individual dual-purpose mounts, which are normally under the direction of senior petty officers designated as MOUNT CAPTAINS. Heavy machine-gun mounts are also directed by mount captains, whose personal responsibilities are chiefly supervisory. At light machine-gun mounts, either the gunners or the range setters may be the mount captains.

Turret officers and mount captains ordinarily direct the guns for which they are responsible under specific orders from battery, sector, or group control stations. In case of casualties, however, they may have considerable independent authority. They must be trained to take full charge of their own stations under local fire control procedures, if and when necessary.

COMMUNICATIONS

An organization can be only as effective as the communications between the various subdivisions. The breakdown of interior communications during battle causes even the most efficient crew to lose its ability to fight the ship effectively.

The development and maintenance of efficient communications is one of the most important phases of a fire control organization. A good organization requires both a satisfac-

Digitized by Google

tory system of telephones and properly trained personnel. The first requirement is met by the sound-powered battle telephone system; the second requirement is met by the use of competent telephone talkers.

It will be your responsibility to teach these men the telephone procedures that you have learned through study and experience. The men you select for telephone talkers must be able to act intelligently in any emergency. They must be familiar with the problems of both their immediate stations and of those with which they are in communication.

Remember that the battle bill is merely the battle organization of your ship set down on paper. It is your chief responsibility, as a leading Petty Officer, to help transform it from an organization on paper to an actual, efficient ship. The success of your ship's battle performance will depend not only upon how well you train the telephone talkers, but upon the personnel who man the fire control equipment as well.

Digitized by Google

Digitized by Google

CHAPTER 2

BALLISTICS AND TABLES

INTERIOR AND EXTERIOR BALLISTICS

The field of INTERIOR BALLISTICS deals with the behavior of projectiles while they are still in the gun. In interior ballistics, you find out the effect of powder composition and temperature on the movement of the shell. You find out the effect of the size and shape of the breech chamber. You find out how thick the gun barrel has to be to withstand the explosion of the propelling charge.

Using the science of interior ballistics, guns, projectiles, and powder charges are designed so that the shell will leave the muzzle of the gun traveling at a definite, known speed. This speed is called INITIAL VELOCITY, or *I.V.* It is the starting point of the science of EXTERIOR BALLISTICS.

Exterior ballistics deals with what happens to a projectile after it leaves the gun. You start with a shell traveling at a known speed—the *I.V.*—and in a known direction. This direction, for all practical purposes, is the direction of the center line or axis of the gun barrel. From then on you have no control over where the projectile goes. But it's mighty important to find out where it's going to go, because if you know "where," you'll know how to position the gun barrel. If you know that the shell is going to curve to the right, you'll train the gun to the left. If you know the shell is going to curve downward, you'll elevate the gun.

Digitized by Google

In other words—you'll solve the fire control problem. That's all there is to it. All the elaborate gear—the directors, the synchros, the servos, the rangekeepers, the integrators, the rangefinders, the power drives—has just one purpose: to find the right position for the gun barrel and to put it in that position.

A HYPOTHETICAL CASE

Start with the simplest possible situation. You're gun captain of the bow gun on Buck Rogers' space ship, anchored in empty space out somewhere between the stars. Out here, far from the earth, nothing has any weight. If you pick up a shell and let go of it, it will just stay where you put it.

So how are you going to lay the gun?

That's easy. The answer is provided by one of the fundamental laws of physics—Newton's first law of motion. This law states that any moving body will continue to move in a straight line at the same speed until something interferes with it. When the projectile shoots out the muzzle of your gun at a speed of, say, 2,700 feet per second, there's nothing to interfere with it. It will simply continue to travel at this speed indefinitely—for hundreds of thousands of miles, maybe—until it hits something.

That makes fire control pretty easy. You don't have to worry about range, deflection, sight angle, superelevation, or anything else. You just sight the gun barrel at the target and press the firing pedal. If the enemy is on the line of the gun axis—and stays there—he'll get hit, no matter how far away he is.

THE PROBLEM OF WEIGHT

But even Buck Rogers doesn't always have it that easy. Suppose he gets his rocket ship underway, heads for the moon, and lands there.

Now your problem is tougher. On the moon, bodies have weight. This means that if you lift the shell and let go of it,

Digitized by Google

it will fall. So will your hat. So will you, if you jump overside. And the surprising thing is that you, your hat, and the shell, will all fall at the same speed. This fact was first discovered by the Italian astronomer, Galileo, about 1600. He dropped several different weights from the top of the Leaning Tower of Pisa and found that they all hit the ground approximately together.

As you know, a falling body falls faster and faster the longer it falls. Each second that it falls it gains a definite amount of speed—about 32.2 ft./sec. (feet per second). This change of velocity, or acceleration, is the same for any body falling to the earth. It is usually written as g. (On the moon, of course, the acceleration would have a different value but that doesn't need to worry you for the present.)

FIRE CONTROL IN A VACUUM

Now get back to the rocket ship, peacefully berthed on the moon. It happens that when the enemy is sighted, the bow gun has been unbolted from the deck and set up on the ground alongside the ship. (Don't ask why. It's just to make the calculations easier.)

Suppose you do the same thing you did before. Line up the axis of the gun straight at the target. As before, the projectile will continue traveling in that same direction and same speed unless something interferes with it.

This time something does interfere—the weight of the projectile. As soon as the shell leaves the barrel, it starts to fall. All bodies, as you know, fall in exactly the same way. So the projectile shot from the gun falls at the same speed, and falls the same distance in any time interval. The only difference is that it's traveling forward, in the direction of the gun axis, at the same time that it's falling. The projectile has two different motions, one forward and one down. You can see what happens in figure 2–1.

If the projectile is going to curve downward when you fire it, it's fairly obvious what you have to do. You've got to elevate the gun. The question is—how much?

Digitized by Google

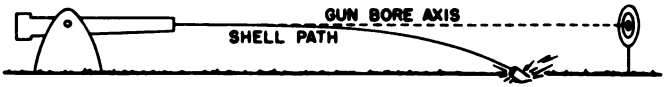


Figure 2–1.—You didn't allow for the weight of the shell.

Suppose you elevate the gun above the horizontal by some angle, E_g, as in figure 2–2. This angle, the gun elevation above the horizontal, is known in ballistics as the ANGLE OF DEPARTURE, and the direction of the gun axis is called the LINE OF DEPARTURE—the line along which the shell "departs" from the gun.

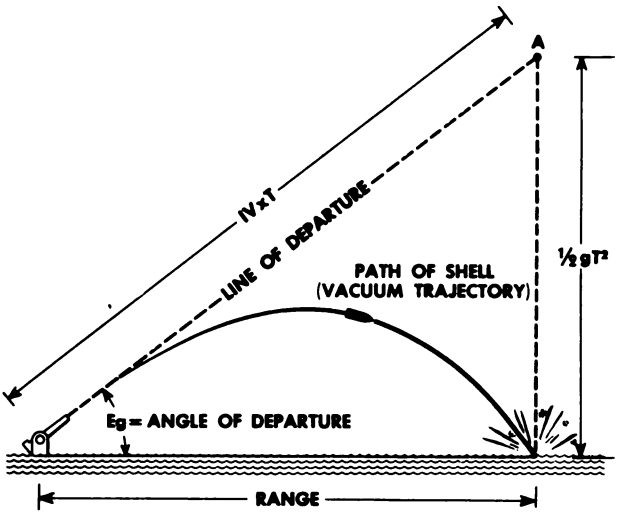


Figure 2–2.—You have to elevate the gun.

With the gun elevated the projectile will still have two motions—a motion along the line of departure at a speed equal to the initial velocity or *I.V.*, and a falling motion straight down at a constantly accelerating speed. Just after it leaves the gun, the shell will be falling quite slowly, so most of its motion will be upward and forward along the line of departure. As it travels farther, it will fall faster,

Digitized by Google

until the falling speed equals the upward speed along the line of departure. This will be the highest point of the shell's path. As it continues to fall, gravity will be pulling it down faster than momentum is carrying it up. Its path will curve downward, more and more steeply, until finally it hits the ground.

The distance from the gun to the point where the projectile hits the ground is the RANGE of the gun. The range is going to change as the angle of departure changes. You can easily see why this is true. When you tilt the line of departure upward, the shell's initial velocity tends to carry it higher. The shell has farther to fall before it hits the ground. It takes longer for the shell to fall to earth, and during this longer time, it has a chance to go farther forward.

But something else is happening too. As the gun elevates, the projectile is given more upward movement--but it's also given less forward movement. If you elevate above 45°, the time the shell is traveling will continue to increase, but the forward movement will be so much slower that, even in this longer time, the shell won't go as far. Obviously, if you shoot straight up, range will be zero. You get maximum range (on the moon) at an elevation of 45°. Typical paths, or TRAJECTORIES, are shown in figure 2–3.

It's quite easy to figure out what the range will be for any

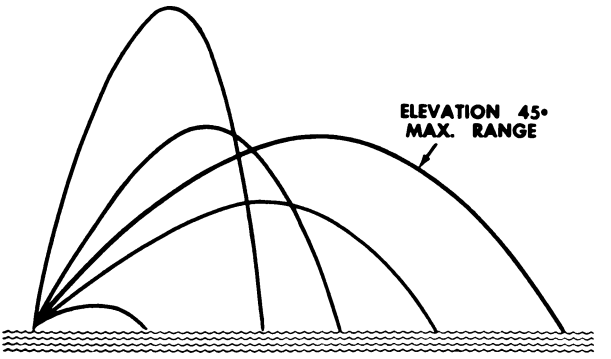


Figure 2–3.—Shell trajectories in a vacuum.

Digitized by Google

particular elevation of the gun. Since the shell has two motions—the *I.V.* and the falling motion—the trick is to consider them separately. You assume that the shell travels along its line of departure for *t* seconds to reach a certain point, and that it is stopped at that point and allowed to fall freely for the same number of seconds. The point it reaches is the same point it would have reached traveling along its trajectory for *t* seconds.

You can see how this works in figure 2–2.

The projectile will reach its full range, of course, at the instant when the distance traveled upward as a result of the initial velocity equals the distance fallen.

By this reasoning you could easily work out a simple formula which would tell you the range of a projectile for any values of *I.V.* and E_θ. There would be one trouble with this formula—it would be true only on the moon!

When you shoot a gun on the earth, the shell has to force its way through air. The air resists its movement and changes the shape of the trajectory in ways to be discussed shortly.

The trajectory of a shell which meets no air resistance might be called the moon trajectory, but in fire control, it's referred to as the VACUUM TRAJECTORY. In actual firing, of course, you never get a vacuum trajectory. But, it's important to understand it, because the air trajectory is determined by making necessary modifications of the vacuum trajectory.

There are several interesting things you should notice about the vacuum trajectory. Its shape is the curve known in geometry as a parabola. The highest point of the curve is in the middle, and it is symmetrical. The angle at which the shell lands—called the ANGLE OF FALL—is equal to the angle of departure. And the speed at which the shell lands—called the STRIKING VELOCITY—equals the *I.V.*

THE EFFECT OF THE AIR

The Navy's wars aren't fought on the moon yet, so when you actually fire a gun you have to send the projectile travel-

Digitized by Google

ing through air instead of through a vacuum. And the air makes the projectile follow a different path from the one it would follow in a vacuum.

The effect of the air is to resist the motion of any body passing through it. That is, when any body is moving through the air, the air will set up a force pushing backward along the line of motion of the body. This force keeps slowing the movement of the body. The shell will lose a certain amount of speed each second and keep going slower and slower.

A peculiar thing about air resistance is that it increases rapidly as the speed of the body increases. Roughly, when the speed doubles, the retardation of the projectile becomes more than four times as great. Thus, if a projectile traveling at 1,000 ft./sec. was retarded 100 ft./sec. every second, a projectile traveling 2,000 ft./sec. might be slowed as much as 400 ft./sec. every second.

With a little thought, you can see what air resistance does to the shape of the vacuum trajectory. When first fired, the forward velocity of the shell is much greater than its velocity up or down. Then the longer the projectile travels through the air, the slower it goes. Shortening of the trajectory will be noticeable at the far end. The high point of the trajectory will not be at the middle, as it is in a vacuum, but will be nearer the point of impact than it is to the gun.

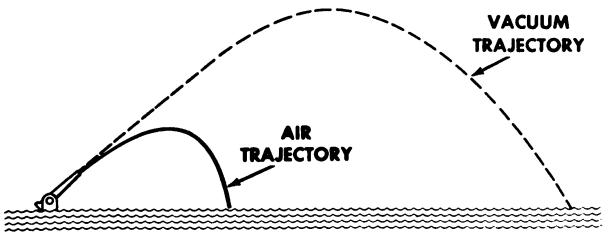


Figure 2–4.—Vacuum and air trajectories.

In figure 2–4, you can see how the trajectory of a shell fired in air differs from that of a shell fired at the same angle

Digitized by Google

of departure in a vacuum. Notice that the range of the shell is much less than the range in a vacuum. In order to give the shell the same range in air that you would get on the moon, you have to elevate the gun much farther, as in figure 2–5.

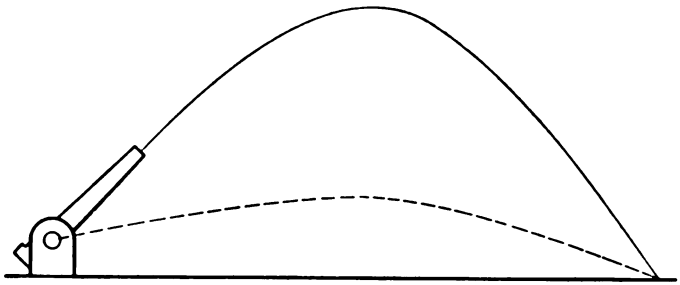


Figure 2–5.—The gun must be elevated farther in air.

Notice, too, that the way the shell lands on the earth is different from the situation when your gun was fired on the moon. There the angle of impact was equal to the angle of departure, and the speed of impact was equal to the *I.V.* On the earth, where the shell has to travel through air, it lands more steeply, so that the angle of impact is greater than the angle of departure. And since it has been losing speed all through its flight, the speed of the shell when it lands will be much less than the *I.V.*

Just how much the shell is slowed up and how much the shape of the trajectory changes from the vacuum form will depend on a number of things.

One thing affecting the trajectory is the DENSITY of the air. Dense air will slow the travel of a shell more than thin air. This complicates the problem quite a bit. Air density depends on temperature and barometric pressure. These values are changing all the time. Moreover, the density is less at points high in the air than it is at sea level. Since the trajectory rises high into the air for a long-range shot, the projectile will be retarded less during each second that it is at the high parts of the trajectory than when it's at the low

Digitized by Google

points. A long-range trajectory will be in thin air most of the time—a short-range trajectory will be in denser air most of the time.

Another thing that affects the shape of the trajectory is the WEIGHT of the shell. The heavier the projectile, at the same *I.V.*, the less it is affected by air resistance. You can see this if you stop to think. Suppose you threw a ping-pong ball and a golf ball at the same speeds. Which would go farther?

The SHAPE of the projectile makes a lot of difference too. Obviously, the bigger around the shell is, the more the air will push against it. A pointed nose makes it easier for the shell to push its way through the air and reduces resistance. Boat-tailing, or tapering, the after end of the shell, as is done on some small-caliber projectiles, has a streamlining effect. Boat-tailing reduces the drag resulting from air turbulence behind the shell.

The effect on the air resistance resulting from the shape of a particular shell is expressed by a quantity called the COEFFICIENT OF FORM. The coefficient of form is determined experimentally—by test firings for each caliber of shell used by the Navy.

FINDING THE RANGE OF A SHELL

Earlier in this chapter you saw that if a stationary gun was fired in a vacuum, the range of the projectile would depend on only two things—

1. The initial velocity.
2. The elevation above the horizontal.

You saw that if you knew these two quantities you could tell just where the shell would land. A simple formula could have been worked out to tell you the elevation you'd need, for any value of *I.V.*, in order to give your shell the range required to hit a particular target.

Such a formula would still have the quantity *I.V.* in it. But naval guns and powder charges are designed to give the same *I.V.*, as nearly as possible, every time the gun fires.

Digitized by Google

So you could have put the known initial velocity of your gun into the formula. Then you would have ended up with a formula telling you the proper angle of departure to use in a vacuum for any range you wanted.

Now, what's the situation in actual gunfire?

You have learned that when a stationary gun fires in still air, the range attained will depend on the following things—

1. The initial velocity.
2. The elevation above the horizontal.
3. The density of the air.
4. The weight of the projectile.
5. The shape of the projectile.

It is possible to work out mathematically the shape of the air trajectory for different values of the above quantities. The computation is quite difficult and can be performed only by men familiar with higher mathematics. When the calculation has been made, it is possible to work out tables giving the range, time of flight, and maximum ordinate (high point) of the trajectory for different values of the above quantities.

The next step is to simplify the tables by taking, for an example, some particular naval gun—say the 5″–38. This gun is designed to have an initial velocity of 2,600 ft./sec. So that value is substituted into the tables. So is the 54–lb. weight of the standard 5–in. shell. And the shape of the standard shell is put into the tables by giving the right value to the coefficient of form.

Finally, a STANDARD ATMOSPHERE is arbitrarily assumed. The standard used provides for a temperature at sea level of 59°F. and a barometric pressure of 29.53 inches. The standard also assumes that the air density decreases, as you go higher in the air, according to a standard formula.

By this method it is possible to determine the values of range, time of flight, and maximum ordinate when projectiles are fired from a particular gun at different angles of departure—provided the conditions are standard.

Digitized by Google

These values have been tabulated for easy reference in a RANGE TABLE for each particular gun. A portion of the range table for a 5″–38 gun firing AA common projectiles is shown in figure 2–6.

As you can see, a great deal of useful information is included in a range table. Some older tables give probable armor penetration in column 9, but this column is omitted from most newer tables.

HOW TO USE THE RANGE TABLE

Notice that column 1 of the range table tabulates a series of ranges in 100–yd. steps. The page illustrated, running from 7,000 yds. to 9,000 yds., is only one of many. The entire range table runs from 1,000 yds. to 18,200 yds.

Column 2 gives the angle of departure of the gun barrel for each range. Column 2 gives the angle in degrees and minutes, while column 2a gives the same angle in minutes (2° equals 120 min.; 3° equals 180 min., etc.) Column 2a is included because the sight angle scales of modern guns are usually calibrated in minutes rather than in degrees.

Thus, suppose you want to hit a target 8,100 yds. away. In column 1 you find 8,100 yds. Opposite 8,100 yds. in column 2, you will find that an angle of departure of 6° 29′.0 is needed to get this range.

So, set that angle of departure on your gun, and you're all set.

Are you, though?

Remember how the range table was constructed. It was based on the assumption of standard *I. V.*, standard air density, and standard projectile weight and shape. So, if conditions are not standard, you'll have to make allowances for them.

EFFECT OF AIR DENSITY

Consider the matter of air density. The range table value of angle of departure will be true only when the condition of the atmosphere is that produced by a 59° F. temperature, a 29.53 in. barometer, and a standard density distribution.

Digitized by Google

INITIAL VELOCITY=2600 F.S. WEIGHT OF PROJECTILE=54 POUNDS.

Range	Angle of elevation			Increase in angle of elevation for 100 yards increase in range	Angle of fall		Time of flight	Striking velocity	Drift	Danger space for a target 20 feet high
1	2		2a	2b	3		4	5	6	7
Yards	°	′	Minutes	Min.	°	′	Seconds	F. S.	Yards	Yards
7000	5	00.1	300.1	7.4	8	14	12.06	1232	22.8	46
7100	5	07.5	307.5	7.5	8	30	12.31	1220	23.8	45
7200	5	15.0	315.0	7.6	8	46	12.57	1208	24.8	43
7300	5	22.6	322.6	7.8	9	02	12.83	1197	25.8	42
7400	5	30.4	330.4	8.0	9	19	13.09	1186	26.9	41
7500	5	38.4	338.4	8.1	9	36	13.36	1175	28.0	40
7600	5	46.5	346.5	8.2	9	53	13.63	1165	29.1	39
7700	5	54.7	354.7	8.4	10	11	13.90	1155	30.3	37
7800	6	03.1	363.1	8.5	10	29	14.17	1146	31.5	36
7900	6	11.6	371.6	8.6	10	47	14.45	1137	32.7	35
8000	6	20.2	380.2	8.8	11	06	14.73	1128	34.0	34
8100	6	29.0	389.0	9.0	11	25	15.01	1119	35.3	33
8200	6	38.0	398.0	9.2	11	44	15.29	1111	36.6	32
8300	6	47.2	407.2	9.3	12	04	15.58	1103	38.0	31
8400	6	56.5	416.5	9.5	12	24	15.87	1095	39.4	30
8500	7	06.0	426.0	9.6	12	44	16.16	1088	40.8	30
8600	7	15.6	435.6	9.8	13	05	16.45	1081	42.3	29
8700	7	25.4	445.4	10.0	13	26	16.75	1074	43.8	28
8800	7	35.4	455.4	10.1	13	47	17.05	1067	45.4	27
8900	7	45.5	465.5	10.3	14	09	17.35	1060	47.0	26
9000	7	55.8	475.8	10.4	14	31	17.65	1054	48.6	26

Figure 2–6.—Range table

Digitized by Google

LENGTH OF PROJECTILE=4.15 CALIBERS. RADIUS OF OGIVE=5.25 CALIBERS.

Maximum ordinate	Change of range for variation of +10 feet per second initial velocity	Change of range for variation of -1 pound in weight of projectile.	Change of range for variation in density of air of -10 per cent	Change of range for wind component in plane of fire of 10 knots	Change of range for motion of gun in plane of fire of 10 knots	Change of range for motion of target in plane of fire of 10 knots	Deviation for lateral wind component of 10 knots	Deviation for lateral motion of gun perpendicular to line of fire, speed of 10 knots	Deviation for lateral motion of target perpendicular to line of fire, speed of 10 knots	Change in height of impact for variation of 100 yards in slant ber
8	10	11	12	13	14	15	16	17	18	19
Feet	Yards	Yards	Yards	Yards	Yards	Yards	Yards	Yards	Yards	Feet
590	37	5	275	31	37	68	22	46	68	43
615	37	5	282	32	37	69	23	46	69	44
640	38	4	289	33	37	71	24	47	71	46
670	38	3	296	34	38	72	24	48	72	47
700	38	2	303	35	38	74	25	49	74	49
730	39	1	310	36	38	75	26	49	75	50
760	39	0	317	38	38	77	27	50	77	52
790	39	— 1	324	39	38	78	27	51	78	54
820	40	— 2	331	40	39	80	28	52	80	55
855	40	— 3	338	42	39	81	29	52	81	57
890	40	— 4	345	43	39	83	30	53	83	59
925	40	— 5	352	44	39	85	31	54	85	61
960	40	— 6	359	46	39	86	32	54	86	63
1000	41	— 7	366	47	39	88	33	55	88	64
1040	41	— 8	373	48	40	89	34	55	89	66
1080	41	— 8	380	50	40	91	35	56	91	68
1120	41	— 9	386	51	40	92	36	56	92	70
1160	42	—10	393	53	40	94	37	57	94	72
1205	42	—11	400	55	40	96	38	58	96	74
1250	42	—12	406	56	40	97	39	58	97	76
1295	42	—13	413	58	40	99	40	59	99	78

for 5-inch gun.

Digitized by Google

The chances are that the air density when you fire has some different value. A value for air density is obtained by the ship's aerological party, on a large ship, or by the navigation department. It will be furnished to the gunnery department in the form of a PERCENTAGE VARIATION from standard density. Of course, the density is different at different altitudes. And the effect of density at any particular altitude depends on whether you're firing a long-range or a short-range shot. Most of the length of a long-range trajectory, you remember, is in the thin upper air. So an average value is worked out for a particular range, which is called BALLASTIC DENSITY for that range.

Now look at column 12 of the range table. It shows the error which will be introduced if the average air density is 10 percent less than standard density. If the density is less, it's obvious that resistance to the movement of the shell will be less, and the shell will go farther. In column 12, opposite 8,100 yds. in the range column, you find a value of 352. This means, that if you set an angle of departure of 6°29′ into the gun, and air density is 10 percent below standard, you will overshoot the target by 352 yards.

Now suppose the density were only 8 percent low. Then the error will be 8/10 of 352 yards. Divide 352 by 10 and multiply by 8, and you get an error of 280 yards.

So what are you going to do about that error?

Since you are shooting over, the logical thing is to aim for a point 280 yds. short of the target. Then the error will put you right on. So take a range of 8,100−280=7,820 yards.

Now your angle of departure should be the 6°03.1′ shown in column 2 for a range of 7,800 yards.

In case there's no aerological party aboard to give you a value of ballistic density, you can work out an approximate air density correction by means of a graphic device called a nomogram. An air-density nomogram is included in most range tables and one is shown in figure 2–7.

Digitized by Google

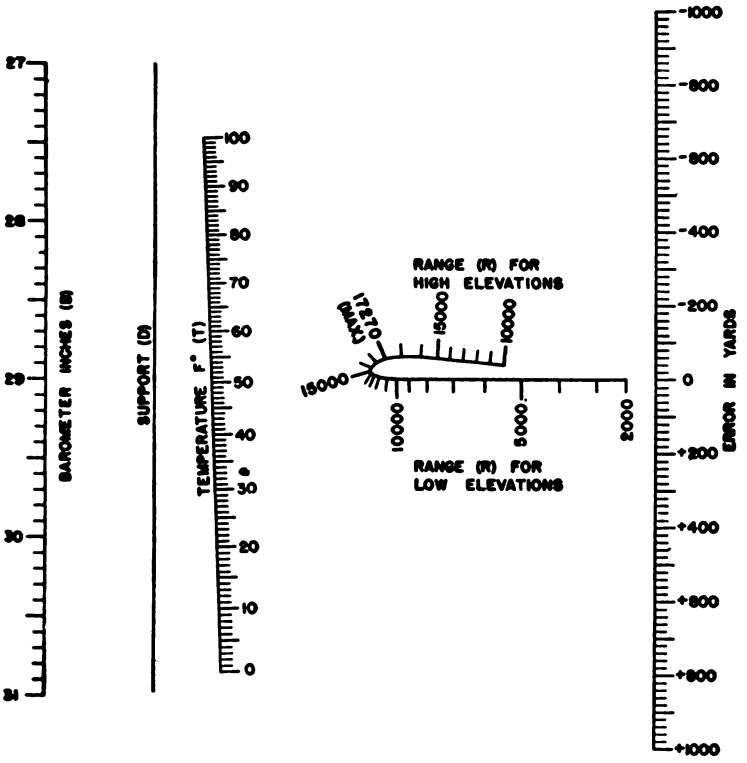


Figure 2–7.—Air density nomogram.

HOW TO USE THE AIR DENSITY NOMOGRAM

To use the nomogram, you lay a ruler between the point on the temperature line corresponding to present air temperature and the appropriate point on the barometer reading line. Mark a mark at the point where the ruler crosses the vertical line labeled "Support D." Now lay the ruler between this point and a point on the line marked "Range (R) for high elevations or Range (R) for low elevation." Mark the spot where the ruler crosses the vertical line marked "Error in Yards."

The spot where the ruler crosses the vertical line marked

Digitized by Google

"Error in Yards" is the error in range due to a nonstandard air density.

Make a correction to range-table range to compensate for this error, and get a revised value of angle of departure.

Now you're right on target if the *I.V.* is normal.

CHANGES IN INITIAL VELOCITY

Think back again of the way the range table was worked out. It was based on an *I.V.* of 2,600 ft./sec. This is the initial velocity that the gun is designed to have, but few guns in the fleet actually develop their designed velocity. There are two reasons for the lower initial velocities obtained in actual firing.

One reason is wear of the gun barrel. Every time the gun is fired, the inside of the barrel is slightly worn away, so that the bore becomes enlarged. This EROSION reduces the pressure behind the shell and lowers the initial velocity. Older models of the 5″–38, for example, began to show a noticeable loss of *I.V.* after about 80 rounds had been fired. By the time 500 rounds had been fired, the loss was more than 65 ft./sec.

For this reason, records are kept of the number of times the gun is fired. In this record, a round of target ammunition using a reduced powder charge is counted as equivalent to a fraction of a service round. The total of service rounds plus target rounds counted in this way is called EQUIVALENT SERVICE ROUNDS. Curves have been worked out experimentally for each type of naval gun showing the *I.V.* loss to be expected after any number of equivalent service rounds.

Another way of doing the same thing is actually to measure the enlargement of the bore with a star gage. Curves are available showing the *I.V.* loss for any amount of enlargement. For example, if the bore of a 5″–38 gun Mk 12 is enlarged 0.04 in., *I.V.* will be reduced about 28 ft./sec. This is a more accurate method than counting rounds fired. The usual procedure is to star-gage guns periodically to get a value of *I.V.* loss, and then to keep track of rounds fired between star-gagings.

Digitized by Google

A second thing that can change *I.V.* is the condition of the powder. With modern manufacturing methods, the chemical composition of smokeless powder doesn't vary much. But powder has a different amount of strength at different temperatures. The warmer it is, the more powerful it is.

Navel guns are designed to obtain standard *I.V.* when the powder has a temperature of 90° F. Every degree that this temperature changes will change the *I.V.* by 2 ft./sec. For instance, if the powder being loaded into any gun has a temperature of 80° F., you know at once that the *I.V.* will be 20 ft./sec. less than the rated value. Since magazine temperatures are supposed to be kept as low as possible, this factor will usually reduce *I.V.* Because powder temperature changes slowly, the average magazine temperature for the past several days should be used.

Combining the results of these two factors—erosion and powder temperature—you get a figure for the total reduction in *I.V.* What are you going to do with it?

Column 10 of the range table gives you the change in range for an increase of 10 ft./sec. in *I.V.* So suppose your figures on gun erosion and powder temperature indicate an *I.V.* loss of, say, 38 ft./sec. Assume, as before, a range to the target of 8,100 yards. You will find in column 10, opposite this range, a value of 40 yards. To find the effect on range of a 38-ft./sec. *I.V.* loss, multiply 40 times 38/10, obtaining 152. This means that if you use the angle of departure given by the range table for an 8,100-yard range, you will undershoot by 152 yards. Obviously, if you are falling short, the thing to do is spot up. Choose a range to a point beyond the target, and the error will put you on.

VARIATION IN THE PROJECTILE

Another assumption that was made in computing the range table was that the weight and shape of the projectile were standard. Modern manufacturing methods are so precise that this will almost always be true. However, in case it should be necessary to fire a projectile of nonstandard

Digitized by Google

weight, column 11 of the range table gives the change in range to be expected if the projectile is reduced in weight by one pound.

FINDING GUN RANGE

So far, you have considered each of the errors in range separately. In practice, of course, you combine them. Thus, in the previous examples you found that variation in air density was causing an error of 280 yards over, while variation in *I.V.* was causing an error of 152 yards short. The combined effect is an error of 128 yards over, or about 100 yards over. An OVER error requires a DOWN correction. So you find angle of departure corresponding to a range of 8,100−100=8,000 yards.

Summing up, what is the procedure for determining the angle of departure of a motionless gun firing is still air?

First, get the best value you can for range to the target.

Second, determine the loss in *I.V.* resulting from gun erosion, and the change in *I.V.* resulting from powder temperature. Combine them, and determine from column 10 the range error resulting.

Third, determine from column 12 the range error resulting from variations in air density.

Fourth, combine these errors, paying careful attention to whether they are short or long.

Fifth, apply a correction to the range to compensate for the total error. This correction will be equal in amount and opposite in sign to the error. That is, a short error requires an UP correction; a long error, a DOWN correction. The total correction is called the GUN BALLISTIC IN RANGE. The resulting corrected range is known as ADVANCE RANGE.

Sixth, from the range table, find the angle of departure corresponding to the advance range.

RANGE-TABLE CALCULATOR

About this time you ought to be wondering whether you're crazy or this book is. You've seen a lot of guns fired,

Digitized by Google

but you never saw anyone fiddling around with a range table.

You may not have seen it, but the range table was there all the same. Things move far too fast in modern battle to take time out for long-winded calculations. But the calculations have to be made. And even though they are done mechanically by computers and rangekeepers, they're the same calculations.

The range tables are right there inside every computer—in the form of ballistic cams. These are cams which are cut so that if the input shaft is rotated by an amount proportional to the range, the cam follower will move an amount proportional to one of the columns of the range table—angle of departure, time of flight, etc.

Figure 2–8 shows a simple device that could be used as a substitute for column 2 of the range table. The crank is turned until the dial reads gun range. Then the upper dial will read gun elevation.

As a matter of fact, by the addition of a couple of multipliers and differentials, a simple computer could be built

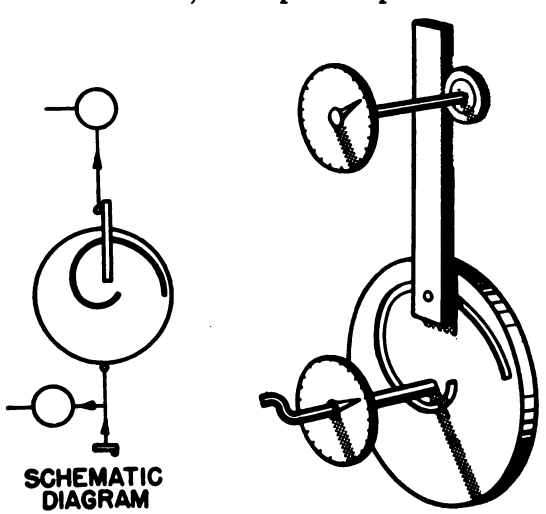


Figure 2–8.—A simple ballistic cam.

Digitized by Google

which would perform the entire calculation as it has been developed so far. Figure 2–9 is a schematic drawing of such a computer. The three cams, two multipliers, and two differentials are represented by conventional sketches. The lines indicate gear-and-shafting connections, with arrowheads showing which is the driven and which is the driving end. The lines, of course, merely indicate that a mechanical connection exists. They do not show where the shafting actually runs.

In this device, actual present range (not gun range), *I.V.*, and air density are set onto the dials by the appropriate cranks. Then the required angle of departure will show up on the right-hand dial.

You will find it interesting to figure out how this little computer does its stuff.

Figure 2–9, of course, does not represent a hook-up that is used in any actual fire control gear. But, it illustrates the

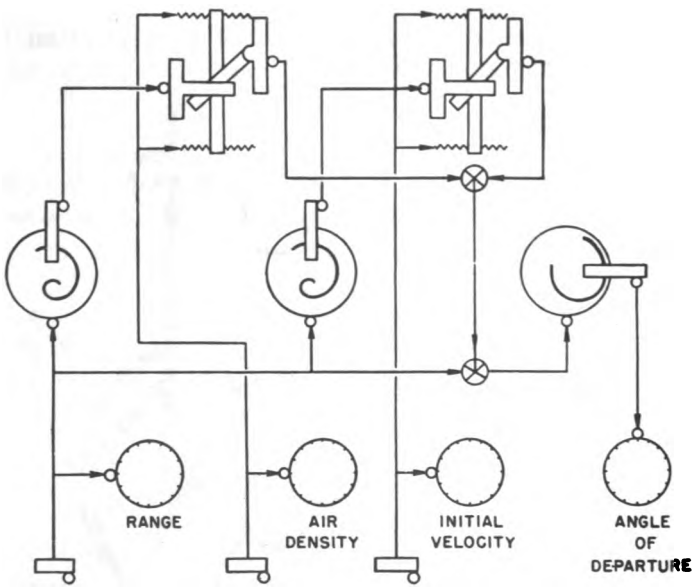


Figure 2–9.—How range table calculations could be made mechanically.

Digitized by Google

principle by which range-table calculations can be introduced into mechanical rangekeepers and computers.

So you see that there are two good reasons why a fire control technician needs a thorough knowledge of the use of range tables and other fire control calculations that you'll come to farther on in this book. The most important reason is that you can't really understand fire control gear unless you understand the mathematical problems that the gear is designed to solve.

The other reason is that the best of gear can suffer casualties. You never know when you may have to lay a gun after your communications with plot have broken down. Then if all you know is how to turn cranks, you'll be helpless.

DRIFT

So far you have found out how to compute the angle of departure, using a range table. So you line up your gun on the target, elevate through the proper angle, and let fly—scoring a clean miss!

What's wrong?

You forgot to allow for drift.

Every shell fired by a U.S. Naval gun drifts off to the right as it travels through the air, and you have to take account of this fact in laying your gun.

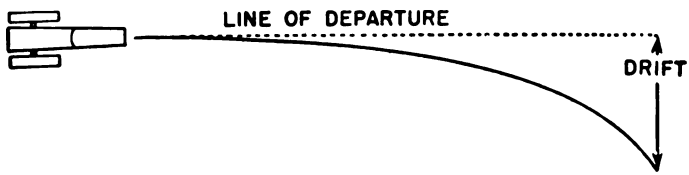


Figure 2–10.—The effect of drift.

Figure 2–10 shows you what this drift looks like. The figure is a plan view of a typical trajectory. Notice how the drift increases with the range. Don't confuse this motion with sideways movements caused by wind. Drift occurs

Digitized by Google

whether there is any wind or not, and it is always to the right in any gun with right-hand rifling. Such rifling gives a clockwise spin to the projectile (looking at the shell from the breech of the gun), and the gyroscopic action resulting from the spin causes drift.

The reason modern naval guns are always rifled is that the gyroscopic action of the spinning shell keeps the projectile pointing almost exactly along its trajectory. This prevents the shell from tumbling in the air and weaving around. It also insures that the shell will land point-first. In addition to this useful effect, however, the gyroscopic action causes the harmful effect of drift. Fortunately, though, any shell drifts by a definite amount which can be determined by experiment and tabulated. Then the gun can be laid to allow for the drift.

The causes of drift are quite complex. There is still disagreement among ballistic experts as to the exact nature of the action of the shell. But allowing for drift in practical gunnery is not at all difficult. By a combination of experiment and computation, the amount of drift to be expected from any trajectory of any naval gun have been tabulated in the range tables.

Column 6 of the range table shows the drift in yards at the target to be expected at any range from the 5″–38 gun.

Using, as before, a range of 8,100 yards, the table shows a drift of 35.3 yards—to the right, of course. To compensate for this, you must deflect the gun barrel to the left by the proper amount.

In order to make this correction, the drift in yards must be converted into an angle in mils. Knowing that a mil is the angle which will cause a deflection of 1 yard at a distance of 1,000 yards, this is easy to do.

A 35-yard deflection at 1,000 yards would be equivalent to 35 mils. Therefore, the mils required to produce a 35-yard deflection at 8,100 yards must be 35/8.1 or 4.3 mils. How this and other corrections are applied will be discussed later along with the computing mechanisms.

Digitized by Google

QUIZ

Select the answer (a, b, c, d, e, f, or g) which BEST completes the statement or answers the question.

1. Which of the following statements is NOT true for the science of exterior ballistics?
   (*a*) It considers the gravitational force acting on the projectile.
   (*b*) It considers the effect of wind, air resistance, and air density.
   (*c*) Initial velocity is the starting point.
   (*d*) The angle of impact is always equal to the angle of departure.

2. Which of the following statements does NOT apply to projectiles shot from a space ship located out between the stars, assuming that this were possible?
   (*a*) Correction for drift can be neglected.
   (*b*) Travel at the same speed throughout its course.
   (*c*) Travel only a limited distance due to air resistance.
   (*d*) The trajectory would be flat.

3. Which of the following does NOT apply to interior ballistics?
   (*a*) Powder composition.
   (*b*) Powder temperature.
   (*c*) Shape of the breech chamber.
   (*d*) Projectile ogive.

4. Which of the following statements does NOT hold true for the vacuum trajectory?
   (*a*) The angle of fall is equal to the angle of departure.
   (*b*) The projectile speed decreases toward the end of the trajectory.
   (*c*) The trajectory is shaped like a parabola.
   (*d*) The *I.V.* is equal to the striking velocity.

5. The angle of departure is the
   (*a*) gun elevation angle above the horizontal.
   (*b*) target elevation angle.
   (*c*) superelevation angle.
   (*d*) angle from the horizontal to the line of sight.

6. At what elevation is maximum range obtained in a vacuum?
   (*a*) 25°.
   (*b*) 30°.
   (*c*) 45°.
   (*d*) 60°.

Digitized by Google

7. If the *I.V.* and gun elevation are the same for each projectile, which of the following projectiles will attain the GREATEST horizontal range?
   (*a*) 16-inch.
   (*b*) 8-inch.
   (*c*) 5-inch.
   (*d*) 1.10-inch.
8. Roughly, when the speed doubles, the retardation of the projectile due to air resistance
   (*a*) doubles.
   (*b*) triples.
   (*c*) quadruples.
   (*d*) remains the same.
9. Which of the following statements is NOT true for an air trajectory?
   (*a*) The high point of the trajectory is nearer to the target than to the gun.
   (*b*) The striking velocity is less than the *I.V.*
   (*c*) The angle of departure is less than the angle of fall.
   (*d*) The shape of the trajectory is a true parabola.
10. In using the air density nomogram, the support is used between the
   (*a*) temperature and barometric scales.
   (*b*) temperature and range scales.
   (*c*) barometric and range scales.
   (*d*) range for high elevation and range for low elevation scales.
11. Enlargement of the gun barrel due to wear from firing is called
   (*a*) bourrelet.
   (*b*) *I.V.* loss.
   (*c*) erosion.
   (*d*) sectional density error.
12. After firing an early type 5''-38 gun 500 times the *I.V.* had decreased by approximately
   (*a*) 30 ft./sec.
   (*b*) 65 ft./sec.
   (*c*) 125 ft./sec.
   (*d*) 500 ft./sec.
13. If 2 ft./sec. per degree F. is allowed for *I.V.* correction, the *I.V.* correction for a powder temperature of 100° would be
   (*a*) plus 20 ft./sec.
   (*b*) minus 30 ft./sec.
   (*c*) plus 30 ft./sec.
   (*d*) minus 20 ft./sec.

Digitized by Google

14. **Which of the following cannot be directly obtained from the range table?**

(*a*) **Drift correction.**

(*b*) **Wind corrections.**

(*c*) **Time of flight.**

(*d*) ***I.V.* correction.**

(*e*) **Erosion error.**

(*f*) **Striking velocity.**

(*g*) **Elevation angle.**

Digitized by Google

Digitized by Google

CHAPTER 3

MECHANICAL MULTIPLIERS

MULTIPLYING CHANGING QUANTITIES

Next time you drop in at your bank, take a look at the machine behind the cashier's window. This machine can add, subtract or multiply in a fraction of the time it would take to do the same operations with a paper and pencil.

In fire control we also have machines to do figuring for us. One is called the MULTIPLIER. The multiplier can multiply two continually changing values to give you a continuous series of answers. You'll need such a series of answers whenever own ship and target are both moving. There are several types of multipliers, and most of them arrive at a solution by using SIMILAR TRIANGLES.

You'll find four types of multipliers in common use—the SCREW, RACK, SECTOR, and CAM-TYPE multipliers. Each has its own advantages which will become apparent as you go through the chapter. We'll start by discussing the construction of each multiplier, and then its theory and application.

SCREW-TYPE MULTIPLIER

Essentially, the screw-type multiplier is constructed of parts already familiar to you, such as gears, racks, slides, and screws. You can see the working parts of the multiplier in figure 3–1.

Digitized by Google

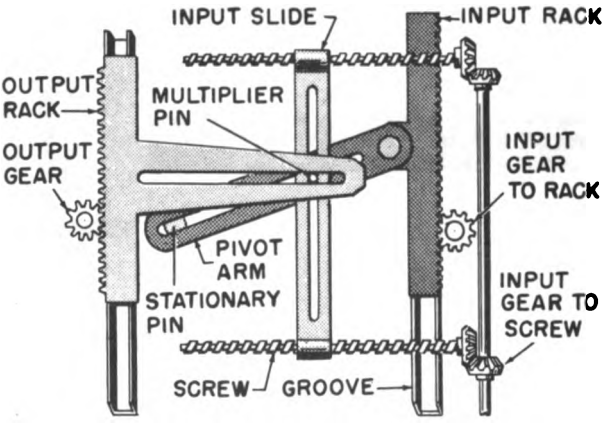


Figure 3–1.—Screw-type multiplier.

The screw-type multiplier has two inputs and one output. The inputs are shaft values which position the input slide and input rack. The output appears at the output rack which positions the output shaft. Thus the output shaft value is always proportional to the PRODUCT of the two inputs.

The slide input gearing is connected to two long screws. These screws pass through the threaded sleeve-like ends of the slotted input slide, and, as the input gears to the screws are rotated, the two screws turn to position the slide left or right. At the same time, the other input positions the input rack up or down, moving the slotted pivot arm around the stationary pin.

The multiplier pin is mounted in the slots of the input slide, pivot arm, and output rack, connecting all three where the slots cross. As the multiplier pin moves with the input slide and pivot arm, it positions the output rack and gear.

The Screw-Type Multiplier Theory

Now that we have examined the construction of the multiplier, let's see how it works.

In figure 3–2 we have moved the input slide and the input

Digitized by Google

rack until the multiplier pin lies directly above the stationary pin. This is the ZERO POSITION of the multiplier.

Now imagine that the screws are rotated, causing the input slide to be moved right. As you can see from the figure, the input slide could be moved throughout its limit of travel without producing any movement of the output rack. In other words, as long as the pivot arm of the input rack is in the position shown in figure 3–2 it is in zero position.

Similarly, let's imagine that the input slide is held in the position shown in figure 3–2. We can then move the input rack up and down. Obviously, since the multiplier pin is directly above the stationary pin, there will be no movement of the output rack. This is the zero position of the input slide.

We have said quite a lot but still haven't found out how the multiplier multiplies. However, it should be clear that there is a zero position for each of the input slides as indicated by the zero lines on figure 3–2. We can also say that the input rack can be on zero even though the input slide is set at some value. Likewise, the input slide can be on zero regardless of the input rack position.

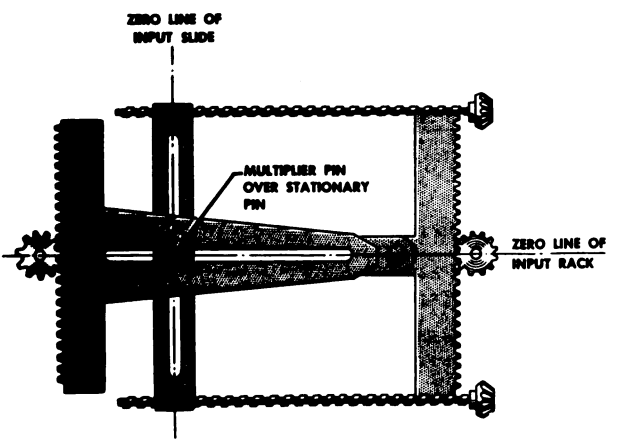


Figure 3–2.—Screw-type multiplier—zero position.

Digitized by Google

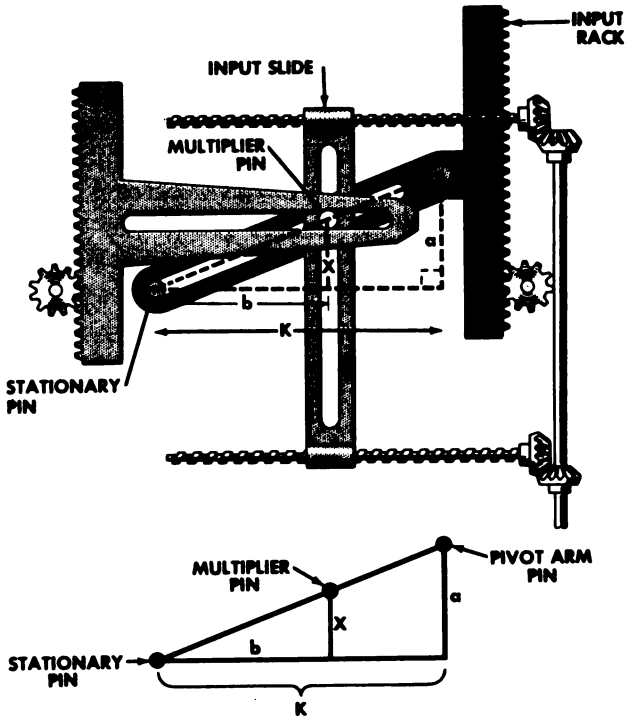


Figure 3–3.—Screw-type multiplier—multiplying positive values.

Locate the pair of right triangles on the schematic diagram of the screw-type multiplier in figure 3–3 and see where they fit in.

Let's examine this figure and list our observations:

1. The distance *b* is the amount the input slide has moved right from its zero position.
2. *a* represents the distance the input rack has been shifted above its zero position.
3. *k* is a fixed distance, since the multiplier pin can't move and the input rack travels in a machined guide rail.
4. The angles *xb* and *ak* are both right angles.

Digitized by Google

5. Finally, x—the quantity we are looking for—is the amount the multiplier pin has moved above the zero reference line k.

From your knowledge of mathematics you will recognize that the triangle formed by xb and the hypotenuse is similar to the triangle ak and the hypotenuse, since both triangles are the same shape and have equal angles.

Knowing that they are similar triangles, we can set up a ratio: x/b in the smaller triangle, is equal to the ratio of height a in the larger triangle to its base k.
That is

$$\frac{x}{b}=\frac{a}{k}.$$

Multiplying both sides by b, we have

$$\frac{bx}{b}=\frac{ba}{k}.$$

Then

$$x=\frac{ba}{k}.$$

This equation means that the distance the output rack has moved from the zero position is equal to the product of the distances the input slide and input rack have moved from zero, divided by a constant.

In other words, THE OUTPUT IS ALWAYS PROPORTIONAL TO THE PRODUCT OF THE TWO INPUTS.

Since k is a fixed distance, it has a constant value in each multiplier. Its effect can be taken care of by the proper choice of input and output gearing for the multiplier.

So far we have discussed only the multiplication of positive quantities. Occasionally it is necessary to multiply a quantity such as cross-level (a correction for roll and pitch of the ship) which has both positive and negative values. This is accomplished by a neat little trick. The position of the stationary pin is shifted as shown in figure 3–4.

You will notice from figure 3–4 that the input slide can be moved either right or left with respect to the position of

Digitized by Google

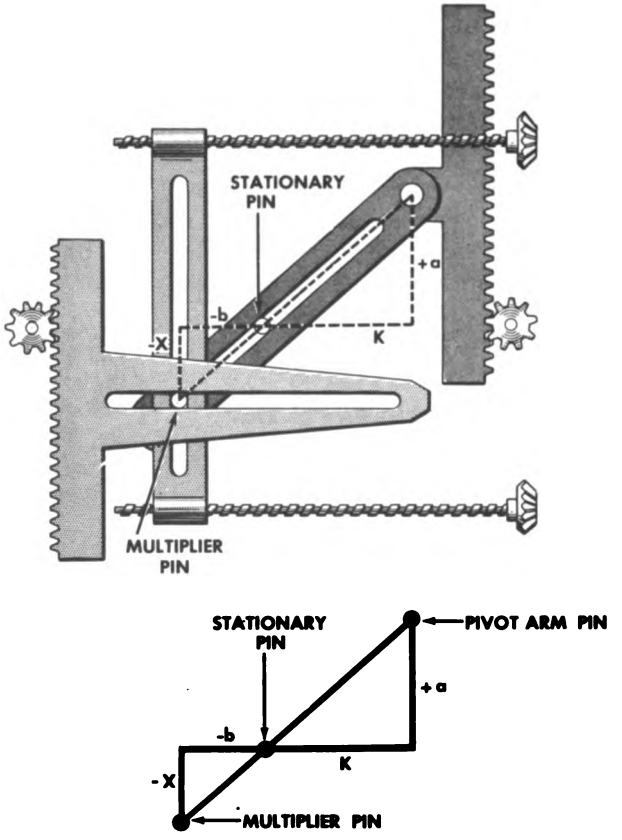


Figure 3–4.—Screw-type multiplier—multiplying negative values.

the stationary pin. If the stationary pin represents zero, this means that both positive and negative values can be introduced on the input slide.

Likewise, the input rack can be positioned above or below the zero reference. That is, a position of the output rack above the stationary pin represents a positive output, and a position of the output rack below the zero reference line represents a negative output.

Digitized by Google

In figure 3–4, the input a on the rack is positive. The slide input b is negative. If we substitute these values in our equation, we have:

$$x = \frac{(+a)\ (-b)}{k}, \text{ or } x = \frac{-ab}{k}.$$

This means that if either input is negative, the output is negative.

You can see from this example that the stationary pin may be located at any convenient place on the multiplier, depending on whether both or only one of the inputs is to have positive and negative values.

There are two things to remember regardless of the position of the stationary pin. If you know them you won't have any trouble with the screw-type multiplier. They are: (1) the zero position of the input slide is always directly over the stationary pin, (2) the zero position of the input rack occurs when the pivot arm lies in the position shown in figure 3–2. In other words, when the pivot arm is at right angles to its input rack, it is also at right angles to the input slide—or on zero.

THE RACK-TYPE MULTIPLIER

The rack-type multiplier in figure 3–5 performs the same task as the screw-type multiplier. The only difference in the rack-type multiplier is that the input slide has been replaced with an input rack, and the output rack is placed on the same side of the multiplier as the second input rack. Otherwise, it is the same as the screw-type multiplier and does the same job.

The two multipliers are also very similar in construction. As you can see from figure 3–5, all three racks are mounted on bearings which ride in the grooved guide-rails. To simplify the diagram, the guide rail for the output rack is not shown.

Input rack No. 1 is mounted on the same side as the output rack so that its slot is at right angles to the slot in the output

Digitized by Google

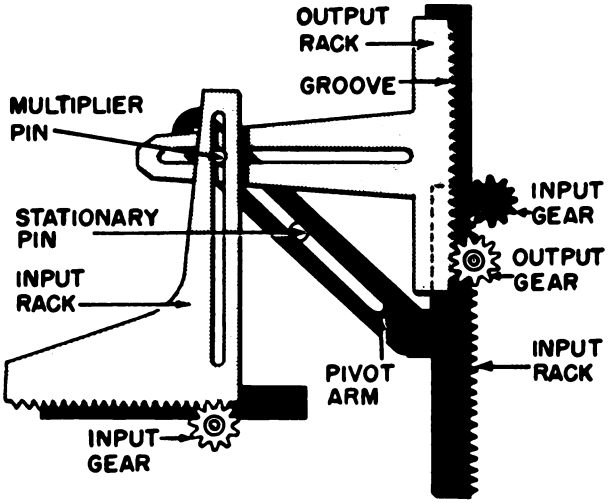


Figure 3–5.—Rack-type multiplier.

rack. The functions of the multiplier pin and stationary pin are the same as in the screw-type multiplier you just studied.

Here is how the rack-type multiplier works. It employs similar triangles just like the screw-type multiplier. The arrangement of the similar triangles can be seen in figure 3–6. Try working them out—the solution is $x=\frac{ab}{k}$. In other words, the output is always proportional to the product of the two inputs, just as in the screw-type multiplier.

The zeroing of a rack-type multiplier is similar to the adjustment of a screw-type multiplier. As with most mechanical computing mechanisms, adjusting the rack-type multiplier is largely the application of common sense and mathematical principles.

Before you make an adjustment, study the diagram until you understand it. In the multiplier equation $x=\frac{ab}{k}$, you can easily see that if either a or b is zero, the output x becomes zero.

Digitized by Google

Start by zeroing the quantity a. From figure 3–6 we can see that if the pivot arm is depressed by rack No. 2, the multiplier pin will be moved down the slot in rack No. 1 which is held by its input gear.

When you have depressed rack No. 2 until the multiplier pin lies on the dotted line k (which intersects the stationary pin), the quantity a becomes zero. In other words, rack No. 2 is in its zero position. Now rack No. 1 can be changed in any direction, and the multiplier output will still be zero because $b \times 0 = 0$.

When rack No. 2 is in its zero position, rack No. 1 can be moved to the left. This will move the multiplier pin left in the slotted pivot arm of rack No. 2 until it lies directly above the stationary pin. This is the TRUE ZERO position of the multiplier, since a and b are both zero. If you hold rack No. 1 in this position, and move rack No. 2 and its pivot arm up and down, there will be no movement of the output rack.

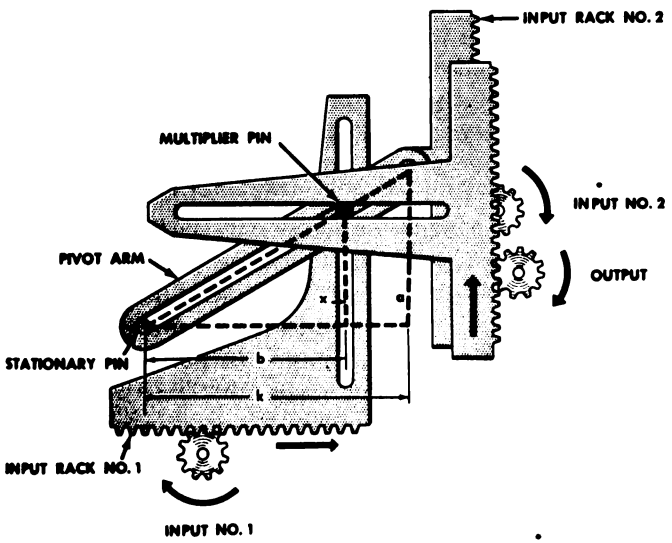


Figure 3–6.—Rack-type multiplier—multiplying positive values.

Digitized by Google

Remember the equation $w=\frac{ab}{k}$. If either a or b is zero, the output of the multiplier is zero.

Here again it is often necessary to multiply quantities which have both positive and negative values. In this case you will find that the position of the stationary pin is moved, just as it was in the screw-type multiplier. If you encounter a rack-type multiplier of this design, don't let it puzzle you. Just follow through the basic formula. You will find the same zeroing procedure.

THE SECTOR-TYPE MULTIPLIER

Now that you understand the construction and theory of the screw- and rack-type multipliers, you won't have much difficulty with the sector-type multiplier. Its construction is slightly different, but it still employs triangles for the multiplication of the two inputs, although in a different way.

A sector-type multiplier is shown in figure 3–7. This multiplier is called the sector-type because the long geared parts are sectors of circles. The centers of these circles are the pivot points around which the sector arms rotate.

As usual, there are two inputs. One input positions the INPUT SECTOR ARM, and the other input turns a long SCREW that is mounted on the input sector arm. The bevel-gear turns this lead screw through a universal joint. The use of the universal joint permits the input to drive the lead screw as the sector arm changes its angular position.

As you can see in figure 3–7, the lead screw drives the multiplier pin up and down the sector arm. Thus the position of the input-sector arm and the position of the multiplier pin on the lead screw represent the two values to be multiplied.

One end of the parallel arm in figure 3–7 is pivoted on the output-sector arm by the connecting pin. The other end is mounted on the radius arm. The multiplier pin moves in the slot in the parallel arm. You can see why the slotted

Digitized by Google

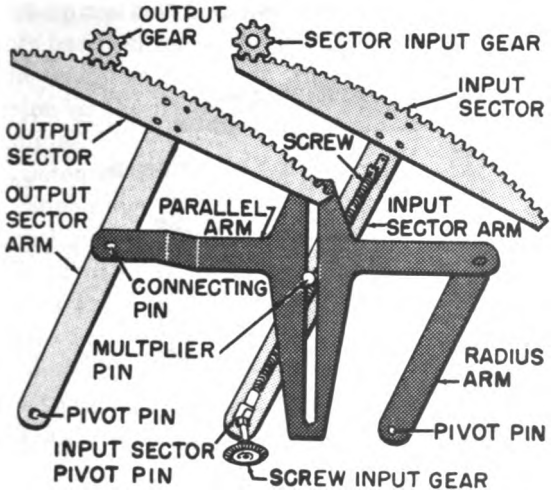


Figure 3–7.—Sector-type multiplier.

piece, which always moves parallel to a line through the three lower pivot pins, is called a parallel arm. Since the slot is at right angles to the parallel arm, it is always perpendicular to the base line.

After examining the construction of the multiplier, we can say that the output-sector arm will move in response to either the movement of the input sector or the movement of the multiplier pin on the sector arm. Of course, if either of the input quantities is on zero, movement of the other input will not produce any output. In other words, just as in the other multipliers you have studied, $b \times 0 = 0$.

Let's see what the zero positions of the multipliers are. Figure 3–8A shows the sector-type multiplier with the input-sector arm in its zero position. You will notice that the lead screw on the input-sector arm is parallel to the slot in the parallel arm. This means the input sector arm is on zero. With the input sector at zero, movement of the pin will not produce any movement of the output-sector arm.

Figure 3–8B shows the multiplier pin on zero. The multiplier pin is on zero when it is directly above the pivot point

Digitized by Google

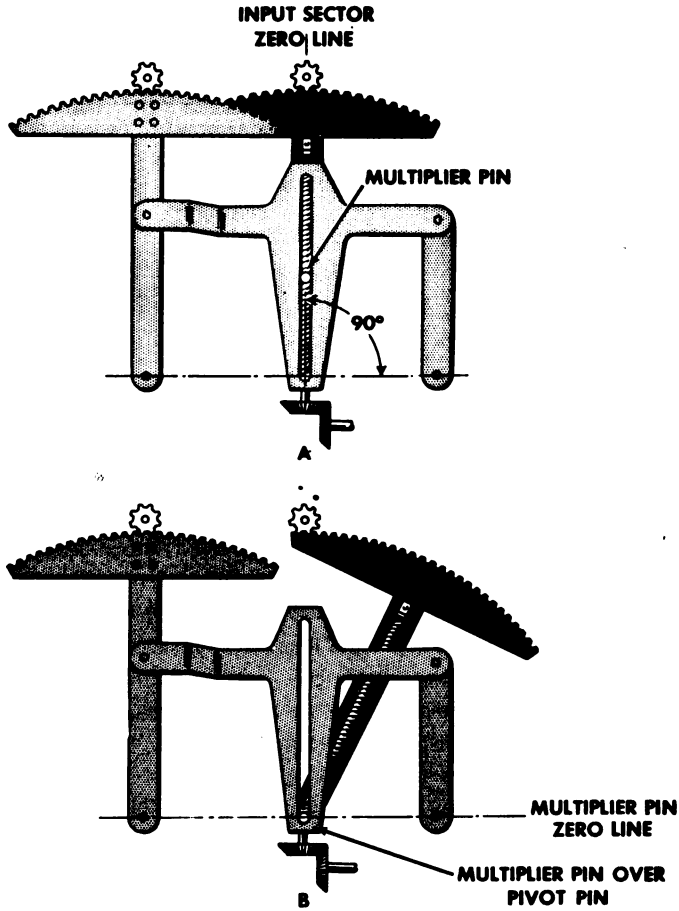


Figure 3–8.—Zero positions of the sector-type multiplier.

of the input-sector arm. When the multiplier pin is on zero, the input-sector arm can be moved through its limits of travel and the output sector will not move.

The theory of the sector-type multiplier should be a cinch after studying the screw- and rack-type multipliers because, like them, it also employs the relationships between triangles when performing a multiplication.

Digitized by Google

Look at figure 3–9 and see how the combination of the two inputs has positioned the sector arm and multiplier pin. Two right triangles have been formed. And, because of the construction of the mechanism, side c is the same length in both triangles.

The hypotenuse k is the fixed length between the pivot pin and the connecting pin in the LEFT-HAND TRIANGLE.

The hypotenuse of the RIGHT-HAND TRIANGLE is the distance a from the pivot pin to the multiplier pin.

From this information we can set up two relationships with which we can explain the action of the multiplier. Remember, the sine of an angle is equal to the opposite side over the hypotenuse. Using this equation we can say that, in the left-hand triangle,

$$\sin D = \frac{\text{side } c}{\text{hypotenuse } k}.$$

Multiplying both sides of the equation by k produces

$$k \sin D = \frac{ck}{k}$$

or,

$$k \sin D = c.$$

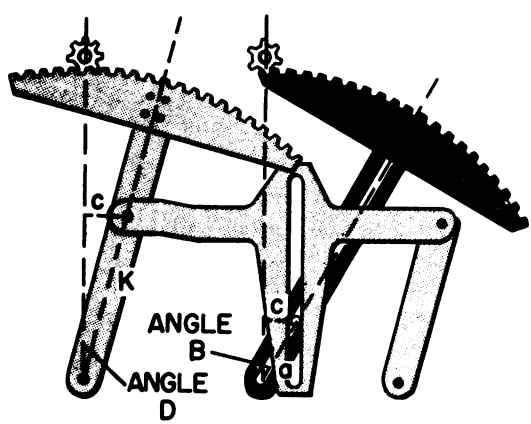


Figure 3–9.—Multiplying with the sector-type multiplier.

Digitized by Google

In the right-hand triangle we can set up a similar equation:

$$\sin B = \frac{\text{side } c}{\text{hypotenuse } a}.$$

Multiplying both sides of this equation by a produces

$$a \sin B = \frac{ca}{a}$$

or,

$$a \sin B = c.$$

Reviewing both equations we have

$$k \sin D = c, \text{ and } a \sin B = c.$$

Since c is the same in both equations, we can set one equation equal to the other. Thus,

$$k \sin D = a \sin B.$$

Dividing both sides of this new equation by k gives

$$\sin D = \frac{a \sin B}{k}$$

the equation you're looking for.

As you will remember from your study of mathematics, it is permissible to substitute the value of an angle in RADIANS for the sine of the angle when the angle is small. In the sector-type multiplier the angle may be as large as 20°. This angle is larger than that usually acceptable if the radian value is to be substituted for the sine. However, the resulting error is still considered acceptable.

If we now substitute the radian values for the sine, the equation becomes:

$$\text{Angle } D \text{ in radians} = \frac{a \text{ times angle } B \text{ in radians}}{k}.$$

Since the radian values can be substituted for the sine values, they also represent the angular values of B and D.

Figure 3–10 shows the substitution of the radian values for the angles.

Digitized by Google

From the previous equation we can say: output D is the product of input a, multiplied by input B, and divided by constant k.

$$D=\frac{aB}{k}.$$

To boil it down, the output is proportional to the product of the two inputs. The constant k is taken into consideration by giving a suitable value to the output shaft, or by appropriate gearing.

Thus, output D is the product of input a multiplied by input B or, $D=aB$.

As you can see from a study of figure 3–7, negative quantities can be introduced on the input sector. However, the multiplier-pin position runs only from zero to positive values as it can't run below the pivot point of the input-sector arm. While the sector-type multiplier can handle both positive and negative inputs on the input-sector arm, the input to the lead screw must always be a positive quantity.

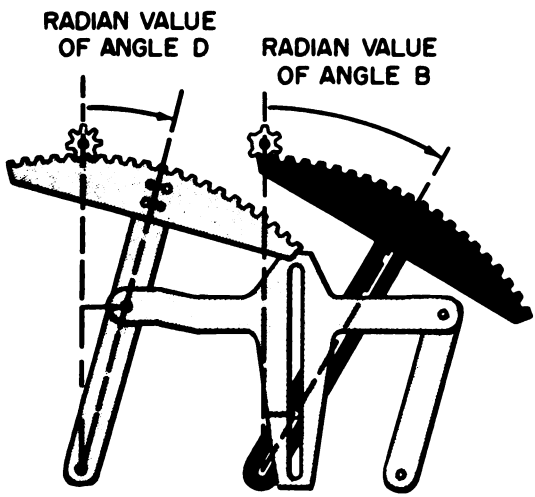


Figure 3–10.—Linear values can be substituted for angles B and D.

Digitized by Google

SINGLE-CAM COMPUTING MULTIPLIER

The single-cam computing multiplier kills two birds with one stone. It computes a function of one value on a cam and multiplies that function by a second value. It is a combination of a cam- and rack-type multiplier. You have studied both the cam and rack-type multipliers, so we'll make short work of this mechanism.

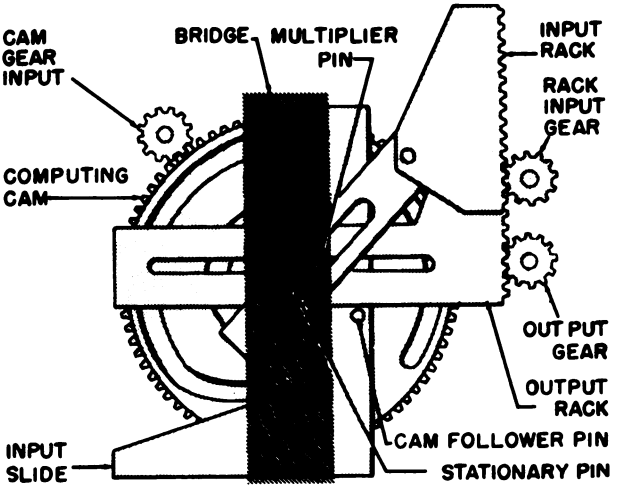


Figure 3–11.—Single-cam computing multiplier.

Figure 3–11 shows all the components of the single-cam computing multiplier. It is like the rack-type multiplier except that one of the inputs is positioned by a CAM instead of a rack. The cam-follower pin is mounted directly on the multiplier input slide. This cam may be cut to compute any desired function of the cam input.

The multiplier works like this. One input drives the input rack through the rack-input gear. The other input drives the cam directly. The cam positions the input slide according to the function for which the cam was cut. Thus the CAM OUTPUT becomes the SLIDE INPUT.

The position of the output rack represents a value which is

Digitized by Google

proportional to the product of the cam output and the rack input, just as in the rack-type multiplier.

You will remember from your study of the rack-type multiplier that the pivot arm was on zero when the output rack and pivot arm were parallel. The same holds true of this multiplier. Figure 3–12A shows the zero position of the pivot arm.

Figure 3–12A also shows the zero position of the slide input, but notice that the slide is not on zero. Instead, it is at its minimum position. This is because this particular cam is cut to represent a secant function which doesn't go to zero. If the cam input did have a zero value, the multiplier pin would be above the stationary pin, just as in the rack-type multiplier.

Suppose both input gears are turned, giving us an input on the rack and an input to the cam, as shown in figure 3–12B. The cam turns and moves the slide a distance b. Distance b is then the OUTPUT of the cam and the INPUT to the multiplier slide. The input rack moves upward from its zero position by the amount a. These two inputs cause the output rack to move up a distance x from zero. Just as before, x is the quantity we are looking for.

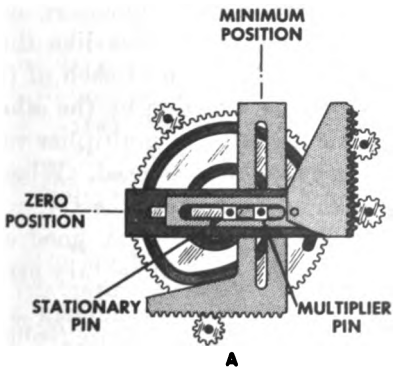


Figure 3–12A.—Zero position of the single-cam multiplier.

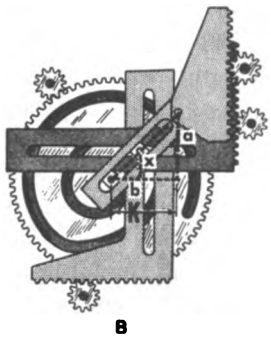


Figure 3–12B.—Multiplying with a cam-multiplier.

Digitized by Google

To sum up then, k is a constant, a is the RACK INPUT, b is the CAM OUTPUT (but is also the SLIDE INPUT), and x is the output of the multiplier. You can see these quantities in figure 3–12B.

These distances form two right triangles. The triangles are just the same as those used for the rack-type multiplier. (See fig. 3–6.) We can set up our equations and solve for x.

$$\frac{x}{b} = \frac{a}{k} \qquad \text{or, } x = \frac{ab}{k}.$$

Here again, since distance k is a constant, we can take care of it by the proper selection of input and output gearing.

To sum up—the multiplier output x is proportional to the output of the cam multiplied by the rack input.

THE TWO-CAM COMPUTING MULTIPLIER

We could carry the cam multiplier procedure a step further. Suppose it were necessary to multiply the outputs of two cams together. We could either use two cams and a multiplier, or we could lump them all together into a two-cam computing multiplier.

This type of multiplier won't be explained in detail in this book because it is very similar to the single-cam computing multiplier. Briefly, though, it operates like this: The two-cam multiplier computes a function of each of the two input values, then multiplies one function by the other.

The adjustment procedure for this type of multiplier varies with the installation and the types of cams used. Wherever you encounter a multiplier of this type, the OP will give detailed instructions for its adjustment. A good example of this type of multiplier is the complimentary error corrector in the Mark 1 computer.

You will encounter all the different types of multipliers we have discussed in this chapter when you are working on fire control equipment. So if you remember the basic things in this chapter you won't have any trouble with multipliers.

Digitized by Google

Before you make any adjustments, study the OP, understand the mechanism, and analyze the trouble. Only after you have done these three things, will you be ready to make your adjustments.

QUIZ

Select the answer (*a*, *b*, *c*, or *d*) which BEST completes the statement or answers the question.

1. Screw type multipliers solve problems by using
   - (*a*) right angles.
   - (*b*) trigonometric functions.
   - (*c*) similar triangles.
   - (*d*) law of sines.
2. Which of the following positions does NOT indicate that the screw-type multiplier is in zero position?
   - (*a*) The pivot arm is directly in line with the output rack.
   - (*b*) The multiplier pin lies directly above the stationary pin.
   - (*c*) The output rack is not moving.
   - (*d*) The pivot arm is at right angles to the input slide.
3. What must be done to the screw-type multiplier if negative quantities are to be used?
   - (*a*) Shift the position of the stationary pin.
   - (*b*) Shift the position of the pivot-arm pin.
   - (*c*) Shift the position of the multiplier pin.
   - (*d*) Shift the position of the input rack.
4. When the rack-type multiplier is at its zero position the
   - (*a*) pivot pin is directly over the stationary pin.
   - (*b*) multiplier pin is directly over the stationary pin.
   - (*c*) multiplier pin is directly over the pivot pin.
   - (*d*) pivot-arm slot is alined with the slot of either output rack.
5. The rack-type multiplier is in true zero position when
   - (*a*) input rack No. 1 is at zero.
   - (*b*) input rack No. 2 is at zero.
   - (*c*) both input racks No. 1 and No. 2 are at zero.
   - (*d*) both input racks are at the maximum travel limit.
6. Refer to figure 3–6. When the pivot arm is alined with the slot of the output rack, the input at input rack No. 1 is
   - (*a*) maximum.
   - (*b*) minimum.
   - (*c*) any value.
   - (*d*) one half maximum.

Digitized by Google

7. In the sector-type multiplier, the input-sector arm can handle
   (*a*) negative inputs only.
   (*b*) positive inputs only.
   (*c*) both negative and positive inputs only when an adjustment is made.
   (*d*) both negative and positive inputs.
8. In the sector-type multiplier, when the multiplier pin is at the bottom of the screw, any motion of the input-sector arm will
   (*a*) cause an equal motion at the output sector.
   (*b*) have no effect.
   (*c*) upset the multiplier zero position.
   (*d*) damage the multiplier.
9. The single-cam computing multiplier is most like which of the following multipliers?
   (*a*) rack-type.
   (*b*) screw-type.
   (*c*) sector-type.
   (*d*) secant-type.
10. In the cam-type multiplier, the output of the cam is also the
   (*a*) rack input.
   (*b*) multiplier output.
   (*c*) slide input.
   (*d*) slide output.

Digitized by Google

CHAPTER 4

COMPONENT AND VECTOR SOLVERS

RESOLVING A VECTOR

Back in the days when flank speed was ten knots and fire control was in its infancy, the Navy used a lot of hand-plotting methods to solve the gunnery fire control problem. With the advent of the airplane and the high-speed ship during World War I, the fire control problem became so complicated that a good guess wasn't accurate enough. About that time the Navy started experimenting with mechanical means of solving the fire control problem. Today, as you can see by looking around your ship, fire control has become a science.

One phase of the fire control problem that will interest you is RESOLVING the motion of own ship into TWO COMPONENTS. This is done so that we will know how much of the motion of own ship affects range to the target, and how much it affects the deflection angle. In other words, we resolve the motion of own ship into two vectors. One of these is called a RANGE COMPONENT, Yo, and the other a DEFLECTION COMPONENT, Xo, of own ship's motion.

The motion of the target and the effect of wind on the projectile are two other factors to be considered. But for the present we will confine our explanation to the movement of own ship.

Since the line of sight to the target is our base line for the solution of the fire control problem, we will break own

Digitized by Google

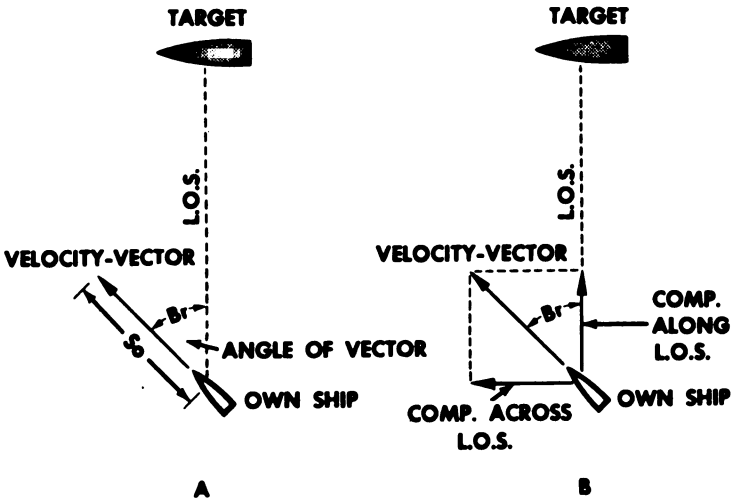


Figure 4–1.—Resolution of own ship speed vector.

ship's movement into components ALONG and ACROSS the line of sight.

You will remember from your courses in mathematics that the course and speed of own ship can be represented by a VELOCITY VECTOR. The length of the vector represents the SPEED of the ship, which is *So*. The direction of the vector, called *Br*, tells you how own ship moves relative to the line of sight, as shown in figure 4–1.

We can then resolve this vector into two components, as in figure 4–2, where one component is ALONG the line of sight and the other arrow is at RIGHT ANGLES to the line of sight.

We can either plot these quantities and measure their lengths, or we can use the relationships of trigonometry to determine their values. In figure 4–2 the vector representing own ship's speed has been resolved into two components by the use of the sine and cosine formulas.

The values of the range and deflection components are easily figured from this triangle:

Digitized by Google

$$\cos Br = \frac{Yo}{So}, \text{or } Yo = So \cos Br$$

and

$$\sin Br = \frac{Xo}{So}, \text{or } Xo = So \sin Br.$$

In other words, Yo, the value of own ship's movement along the line of sight, will always have the value of the

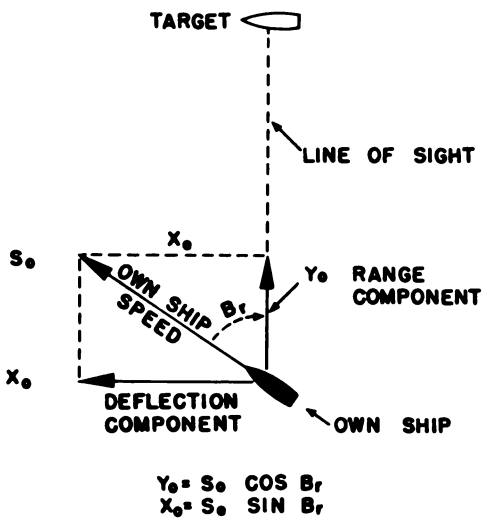


Figure 4–2.—Resolution of vectors by trigonometry.

vector times the cosine of the angle. The value of own ship's movement across the line of sight, Xo, will always have the value of the vector times the sine of the angle.

THE CAM-TYPE COMPONENT SOLVER

The own ship vector we have discussed above can be resolved into components in a number of different ways. One method of vector-resolution uses the cam-type component

Digitized by Google

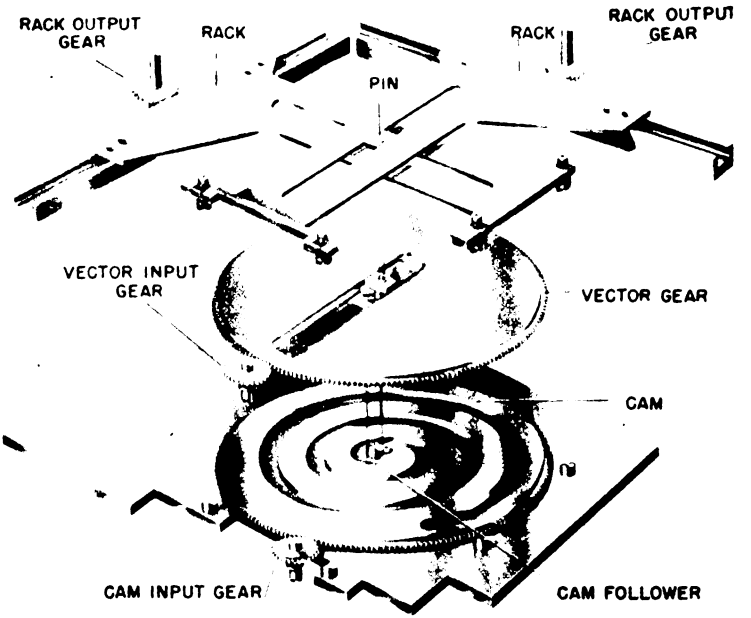


Figure 4–3.—Cam-type component solver, exploded view.

solver. Figure 4–3 shows an exploded view of the cam-type component solver.

The cam-type component solver has five main parts: a SPEED CAM, a VECTOR GEAR, a PIN, a CAM-FOLLOWER and two RACKS. Let's examine each part in detail.

The speed cam has a CONSTANT-LEAD spiral groove. Although it is not indicated in the drawing, the constant-lead cam is called the SPEED CAM or SPEED GEAR. The amount it is turned by the cam input gear represents ship's speed. It turns in one direction when the ship's speed increases, and in the other direction when the ship's speed decreases.

The position of the VECTOR GEAR, which is mounted directly above the speed gear, represents the direction of own ship's movement relative to the line of sight as shown in figure 4–4.

Digitized by Google

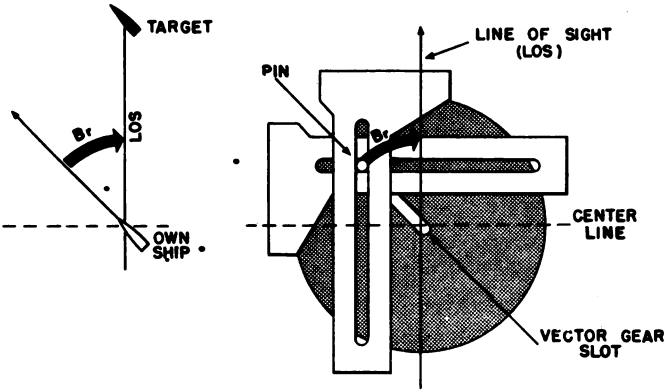


Figure 4–4.—The angle determines the position of the Vector gear slot.

The straight slot, passing through the center of the gear, turns with the vector gear. The angle between a center or zero line of the component solver and the straight slot always represents relative target bearing, *Br*, in the own ship component solver. Relative target bearing is always measured in the horizontal plane. It is the angle measured clockwise from the bow of own ship to the line of sight.

The PIN is joined to a block which also carries the cam follower. The FOLLOWER is offset a little from the pin so that the pin is over the center of the cam when the follower is near the inner end of the cam groove. This offset is introduced to keep the cam follower from getting stuck at the

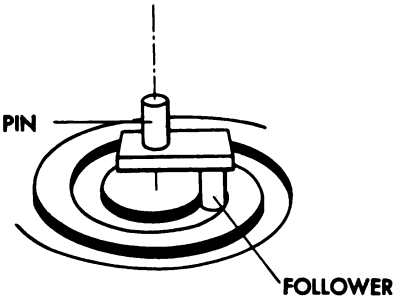


Figure 4–5.—The cam follower and pin.

Digitized by Google

center of the cam. If the groove in the cam were cut to the center of the cam, it would be impossible to back the cam follower out, once it had reached the center.

The FOLLOWER rides in the CAM GROOVE, and the pin comes up through the slot in the vector gear so that the pin is moved by both the cam and the vector gear (see fig. 4–5). It is moved radially by the cam, and angularly by the vector gear.

The two RACKS are pushed back and forth along their guides by the pin. (Notice in figure 4–3 that the racks ride on bearings in machined guide rails, and that they move at right angles to each other.) This movement of the racks rotates the two OUTPUT GEARS. Their outputs are the two components—*Xo*, or movement across the line of sight, and *Yo*, or movement along the line of sight.

Let's briefly review the action of the cam-type component solver. The input gears turn the cam and the vector gear. The cam and the vector gear move the pin. The pin pushes the racks into position. The racks in turn rotate the output gears, giving us our two components of own ship motion.

Solving Own Ship Components

Now that you understand the construction of the cam-type component solver, let's dig into its theory. Before the component solver can solve a problem it must have a vector. Figure 4–6A illustrates a typical problem of resolving the own ship speed vector into its range and deflection components.

As shown in figure 4–6B, the problem has been superimposed on the component solver. Briefly, here is what the component solver must do. It must set up a vector of the ship's motion, and must solve the components of that vector. The two components needed are: speed along the line of sight for range changes, and speed across the line of sight for deflection changes.

In figure 4–6B the pin has been moved from the center of the cam a distance that is proportional to *So*. The vector

Digitized by Google

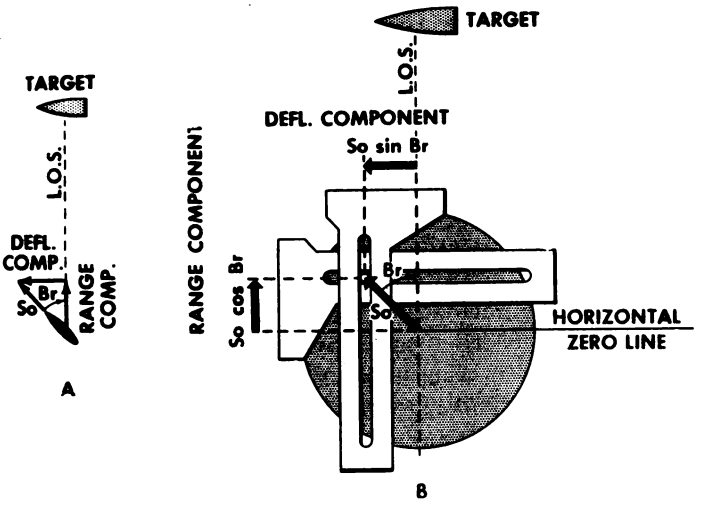


Figure 4–6.—Solving own ship components—1.

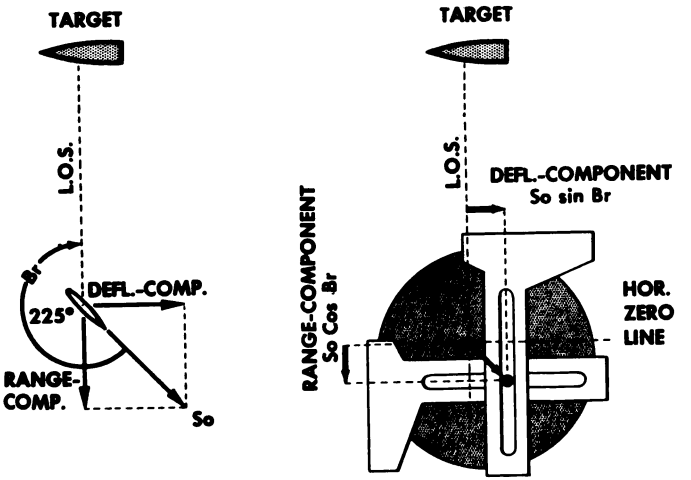


Figure 4–7.—Solving own ship components—2.

Digitized by Google

gear has been rotated through the angle *Br*, or relative target bearing. Notice that the angle made by the slot in the vector gear and the line of sight is the angle *Br*. The movement of the pin from the center of the cam has moved the two output racks by amounts which are proportional to the RANGE and DEFLECTION COMPONENTS of own ship's motion.

The deflection component will be *So* sin *Br*, and the range component will be *So* cos *Br*.

Notice in figure 4–6B that both racks can be moved to either side of their zero positions. This means that the component solver can compute positive or negative values of both the range and deflection components. Figure 4–7 illustrates vector resolution where own ship is going away from the target, and relative target bearing is 225°.

If we assume that our ship is steaming directly toward the target, what will be the output of own ship component solver? Let's look at our formula, $Xo = So$ sin *Br*. Since relative target bearing *Br* is zero, *Xo* is also zero. However, the range component will be a maximum, since $Yo = So$ cos *Br*, where the value of cos *Br* for 0° is one. In other words, if our ship is steaming directly toward or directly away from the target, the deflection component is always zero, but the range component is EQUAL to own ship's speed.

Let's suppose the reverse is true, and that relative target bearing is either 90° or 270° What happens now? The range component of own ship's motion is ZERO because the cosine of 90° or 270° is zero. But the deflection component of own ship's motion is equal to the speed of own ship because the sine of 90° or 270° is equal to one or minus one respectively.

The range component *Yo* of own ship's movement is considered POSITIVE if your ship is moving toward the target. Conversely, *Yo* is considered NEGATIVE if your ship is moving away from the target.

You will learn more about these positive and negative values when you study the fire control problem and gun orders in a later chapter.

Digitized by Google

The Compensating Differential

By now you should be pretty familiar with the cam-type component solver, so let's explain one very important detail that we haven't discussed yet—the COMPENSATING DIFFERENTIAL used with the cam-type component solver.

So far we have treated the inputs to the speed cam and the vector gear as if they were independent of each other. Actually they are not. A moment's thought will tell you why. Suppose that the speed cam was held stationary, and the vector gear was rotated—what would happen? The cam follower would be moved along the spiral groove as the sector gear rotates (as shown in fig. 4–8), and any change in the position of the vector gear would change the speed setting.

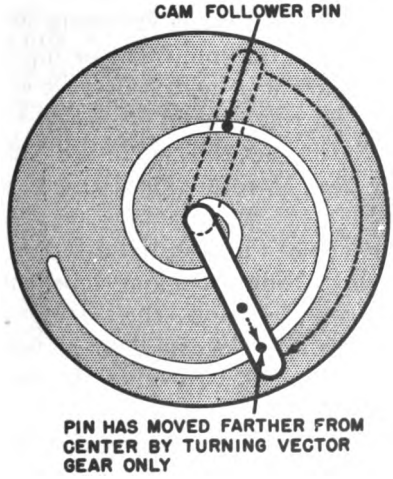


Figure 4–8.—The vector gear affects speed-pin position.

If this condition were allowed to exist we would have an unreliable component solver—in fact, it wouldn't work at all. However, if we rotate the speed cam by the same amount, and in the same direction as the vector gear (whenever a change in relative target bearing is introduced), then own

Digitized by Google

ship's speed won't be changed. This is accomplished by the compensating differential.

Figure 4–9 is a schematic diagram showing the method of connecting the compensating differential in the input gearing of the vector solver.

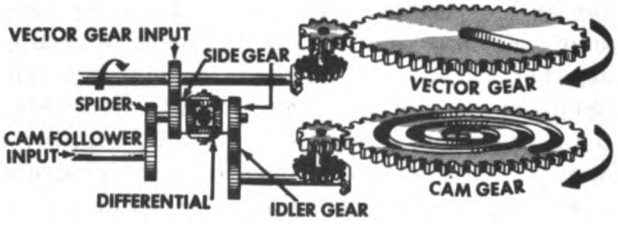


Figure 4–9.—The compensating-differential.

Let's imagine that our ship is changing course, but not speed. This means that the cam-follower input will be held stationary. To see how it is held, let's trace a change in the ship's course through the gearing from the vector-gear input on the left. Notice that rotation of the vector-gear input causes the vector gear to rotate clockwise as shown by the arrows.

Now follow the signal through the differential. The signal drives through the side gears and comes out as the same value, but in opposite direction—the idler gear changes its direction and applies it to the cam gear, causing it to rotate clockwise the same amount. In other words, any input to the vector gear moves the cam gear in the same amount and in the same direction. Thus, any changes in the ship's course won't affect ship's speed.

Summing up, the total effect of the compensating differential, when used with the cam-type component solver, is this: The vector gear is turned only by vector inputs, and the speed cam is turned by either the cam-follower inputs or the vector inputs. Thus, the vector gear can be turned without disturbing the speed value represented by the speed-pin position.

Digitized by Google

Adjustment of the Cam-Type Component Solver

The adjustment of the cam-type component solver is easy if you remember the two basic formulas—$Yo = So \cos Br$ and $Xo = So \sin Br$. You have already learned about the zero positions of the component solver, so let's run through the adjustment procedure.

If you learn the proper method of adjusting one component solver, you won't have any trouble with the rest. Even though the component solver may be either the cam-type or computing-cam-type, the principles involved are the same. Figure 4–10 shows a simplified arrangement of a cam-type component solver used to resolve own ship's course and speed into range and deflection components. It's the same solver you studied earlier in this chapter.

Before you start adjusting the component solver, there is one thing you must watch for—the location of the adjustment coupling on the vector input. If this coupling is located between the compensating differential and the solver (location *c* in fig. 4–10), you must be sure to adjust the vector

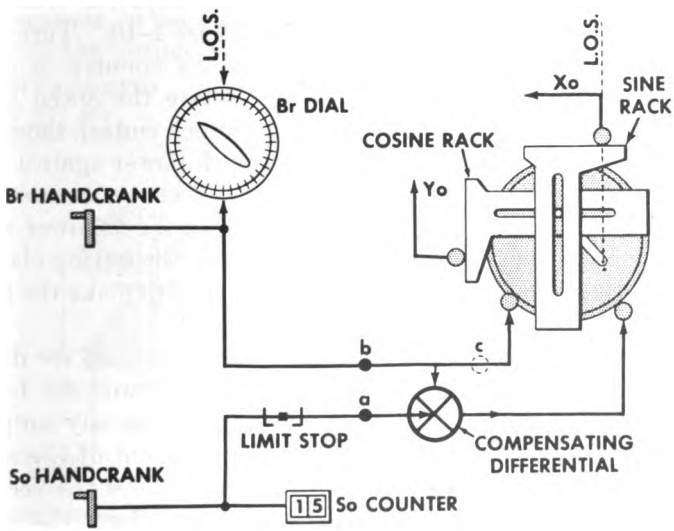


Figure 4–10.—Own ship's component solver.

Digitized by Google

input before the speed input; otherwise, the vector adjustment will move the speed pin without moving the speed counter or dial, thereby upsetting the speed adjustment.

If the vector-input adjustment is located at point *b* in figure 4–10, then either *Br* or *So* can be adjusted first because one adjustment won't affect the other. Before you make any adjustments, consult the OP for the equipment and locate your adjustment points. Know whether one adjustment affects the other.

First of all, make a rough adjustment on the *Br*, or angle-gear input. Turn the *Br* handcrank until the *Br* dial reads zero. Wedge the *Br* input. Loosen adjustment *b* and rotate the vector gear until the vector slot points in the correct direction for the zero setting. The vector slot should now be parallel to the cosine rack. Then slip-tighten the adjustment clamp and remove the wedge. The adjustment procedure for each computer will tell you how to locate the zero position of the vector gear.

Once you have made a rough adjustment on the angle gear, the next step is to make preliminary adjustment of the speed input. Loosen adjustment *a* in figure 4–10. Turn the own ship's speed handcrank until the *So* counter or dial reads zero. Wedge the *So* input. Rotate the speed cam until the cam follower travels to the inner end of the cam groove. ***Caution:*** Never force the cam follower against the end of the groove; ALWAYS TURN THE SPEED CAM SLOWLY. Then back the speed cam off a little so that the follower will not hit the end of the groove. Slip-tighten the setting clamp and remove the wedge. Now you are ready to make the fine adjustments of both inputs.

To refine the setting of the VECTOR GEAR, set the *Br* dials to zero and wedge the input. Now if we crank *So* from zero to its maximum value, there shouldn't be any output on the *Xo* or SINE RACK. If there is movement of the sine (deflection) slide, loosen adjustment *b* and adjust the vector gear until the movement of *So* no longer affects the sine rack. This adjustment must be very accurate, and is

Digitized by Google

usually checked with a DIAL INDICATOR or some other precision method.

Once you have refined this adjustment and tightened the clamp, you should check it at 90°, 180°, and 270°. First, set the *Br* dials to read 180°; *So* sin *Br* is still zero. Movement of the speed cam shouldn't produce any output on the *Xo* slide.

Second, if you set the *Br* dials to either 90° or 270°, and move *So* from zero to its maximum value, there should be no movement of the RANGE-RACK (cosine rack)—all the movement should be on the DEFLECTION-RACK (sine rack). Remember: When *Br* is equal to 90° or 270° *So* sin *Br* is equal to *So* times ± one, because the sine is one, or minus one, and *So* cos *Br* is equal to zero because the cosine of 90° or 270° is zero.

The fine adjustment of the SPEED INPUT (*So*) comes directly from these same formulas. When *So* is zero, movement of the vector gear should produce no movement of either output slide.

To make the fine adjustment of the speed input, set the *So* counter to zero and rotate the *Br* input through 360° Watch the output racks—there should be no movement on

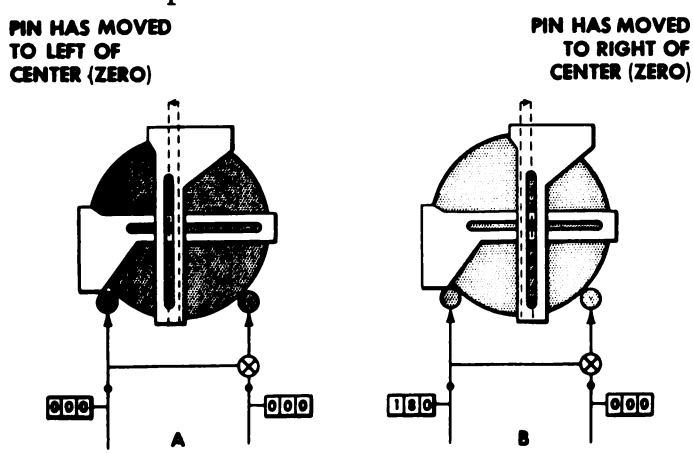


Figure 4–11.—Zeroing the speed input.

Digitized by Google

either rack. If there is, loosen adjustment *a* as before, and wedge the input.

Before you make the fine speed input adjustment you have to determine which direction to move the input to the speed cam, so the following procedure is used. In figure 4–11A, we have positioned the *Br* dials on zero. Since there is an error in the speed input, the cosine slide is located LEFT of its zero line. So let's mark its present position. Now rotate the angle gear until *Br* reads 180°, as shown in figure 4–11B. The cosine slide is now to the RIGHT of its zero position.

The next thing is to correct the speed input. Rotate the speed cam in such a direction as to move the cosine rack back halfway to its position as shown in figure 4–11A. In other words, you HALVE the movement of the cosine rack, thereby locating the zero position of the speed cam. Tighten adjustment *a*. (See fig. 4–10.)

Finally, test your adjustment by rotating *Br* through 360° again. If there are still slight movements of the output slides, the adjustment *a* will have to be refined again. This procedure is repeated until there is absolutely no movement on either output slide. Always bear in mind that these are PRECISION ADJUSTMENTS—a small error here may make a big error in the gun-train and gun-elevation orders.

You may think we have spent a lot of time on the adjustment procedure of the cam-type component solver, but if you know the adjustment procedure for this one, you won't have any trouble with other types—they are all similar.

The component solvers that resolve own ship and target motion into components, in and across the line of sight, are called the primary component solvers. All the corrections that go to make up gun orders are based on these component solvers.

Bear this in mind: Make your adjustments accurately—never force mechanical parts, as you may damage the mechanism.

Digitized by Google

COMPUTING CAM-TYPE COMPONENT SOLVER

Component solvers, like multipliers, have many variations. One variation is the addition of a computing cam, as shown in figure 4–12. Suppose we had to compute the problem necessary for parallax corrections to gun orders. It is equal to $\frac{1}{\text{range}}$ times the sine of the gun-train angle. This problem can be solved in two ways: (1) run range through a reciprocal cam and use the output of the cam to position the speed cam of a component solver, or (2) replace the uniformly cut speed cam with a reciprocal cam and call it a computing-cam component solver.

Obviously, the second method would be easier and would require less space in the rangekeeper. Figure 4–12 is an exploded view of the computing cam-type component solver.

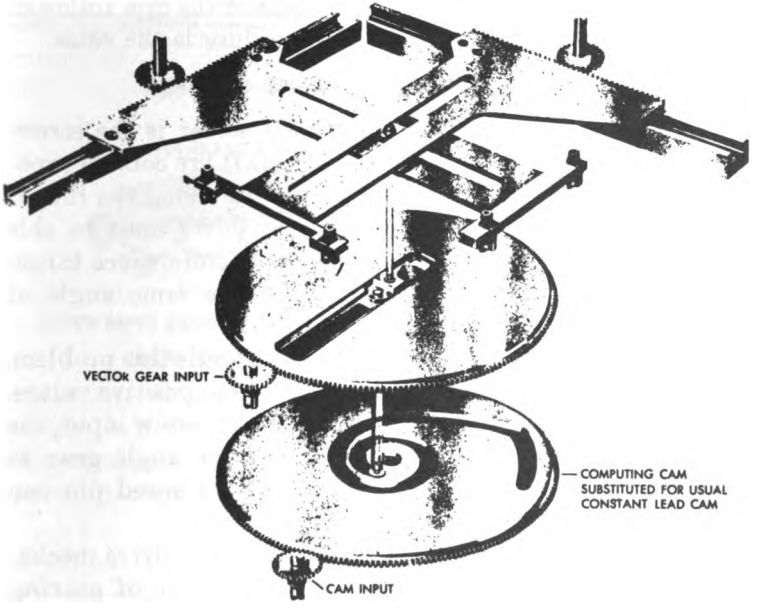


Figure 4–12.—Exploded view of computing cam-type component solver.

Digitized by Google

Notice that its construction is exactly the same as that of own ship's component solver with one exception—the speed cam has been replaced by a reciprocal cam.

Let's examine the inputs and outputs. The inputs are advance range and the gun-train angle. The reciprocal cam output is $\frac{1}{\text{range}}$. The length of the vector, therefore, will always be $\frac{1}{\text{range}}$. The outputs are $\frac{\sin \text{ train angle}}{\text{range}}$ and $\frac{\cos \text{ train angle}}{\text{range}}$. You will learn more about these formulas when you study parallax.

The adjustment procedure for this component solver is similar to that of own ship's component solver. Whenever it is necessary to adjust a component solver of this type, consult the OP. It will give you values of range that correspond to the minimum and maximum positions of the cam follower. Once you know these values, the procedure is the same.

SCREW-TYPE COMPONENT SOLVER

Another variation of the component solver is the screw-type component solver. In the antiaircraft fire control problem, an airplane can be climbing or diving along the line of sight. This means that the component solver must be able to resolve positive and negative target vectors, since target speed can be positive or negative for the same angle of elevation.

The cam-type component solver can't handle this problem, because the speed cam runs only from zero to positive values. However, if we replace the speed cam with a screw input, the speed pin can travel across the face of the angle gear as shown in figure 4–13. In other words, the speed pin can travel in both directions from the zero position.

Figure 4–14 is a cutaway view of the screw-drive mechanism. The speed-input gear drives a long line of gearing which turns the screw. As the screw turns the pin moves, changing the length of the vector. Notice that the pin can

Digitized by Google

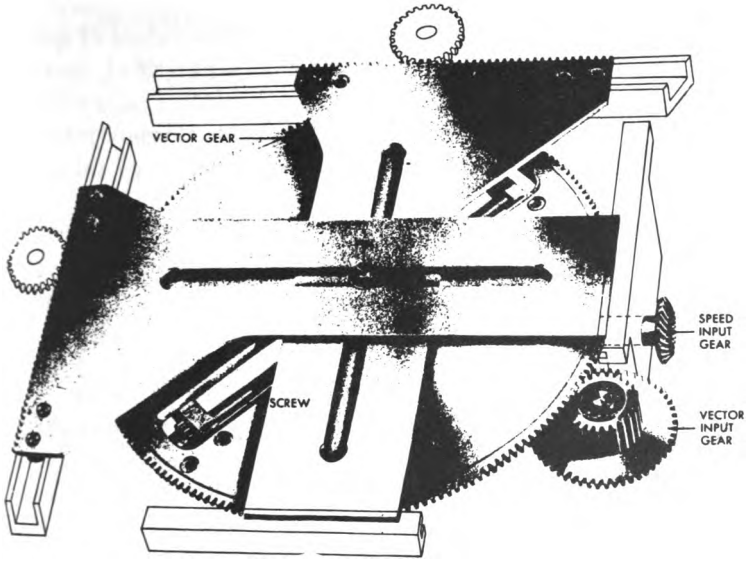


Figure 4–13.—Screw-type component solver.

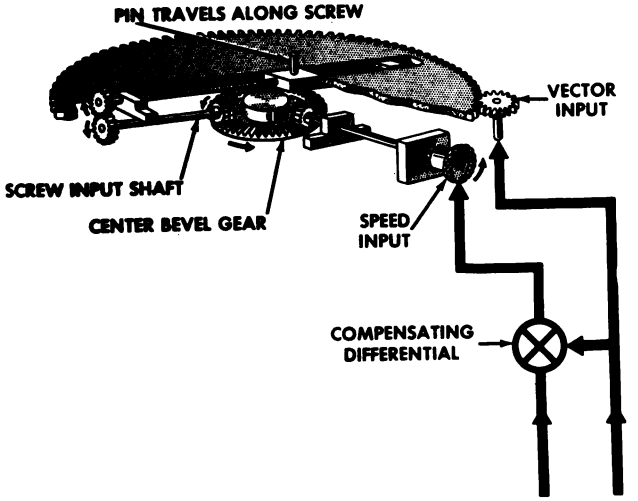


Figure 4–14.—Screw-drive speed input.

Digitized by Google

travel almost the full width of the vector gear. Therefore, the pin position can represent plus or minus values of speed.

Here, too, we need a compensating differential, because changes in the vector-gear position cause the screw-input shaft to walk around the center bevel gear, thereby rotating the screw-input shaft and changing the position of the speed pin.

The compensating differential introduces any changes in angular position of the vector gear through the speed-input shafting. Consequently, the center bevel gear is rotated through the same angle and compensates for the rotation of the screw-input shaft around the center bevel gear.

To boil it down, the angle or vector gear is turned only by vector inputs, and the speed input is turned by speed inputs plus vector inputs. In this way the vector gear can be turned without disturbing the value represented by the position of the speed pin.

You will find that the adjustment of any fire control apparatus is much easier if you thoroughly understand the problem solved by the mechanism. The screw-type component solver is no exception, so let's examine its particular function in the fire control problem.

Suppose we have a plane flying along on a level course but at a high elevation. Before we can fire the guns with any hope of knocking it down, we must know what portion of its speed is affecting the RANGE, and what component is affecting GUN ELEVATION.

A study of figure 4–15 will show you how the screw-type component solver resolves the horizontal range rate, called *dRh*, into components in and at right angles to the elevated line of sight. The term *dRh* (horizontal range rate) is equivalent to the horizontal component of target speed. In the figure *dRh* is equal to target speed because the plane is flying on a level course. You'll learn more about *dRh* later.

In figure 4–15A the plane is approaching own ship, and in figure 4–15B it is going away. The elevation angle *E* is

Digitized by Google

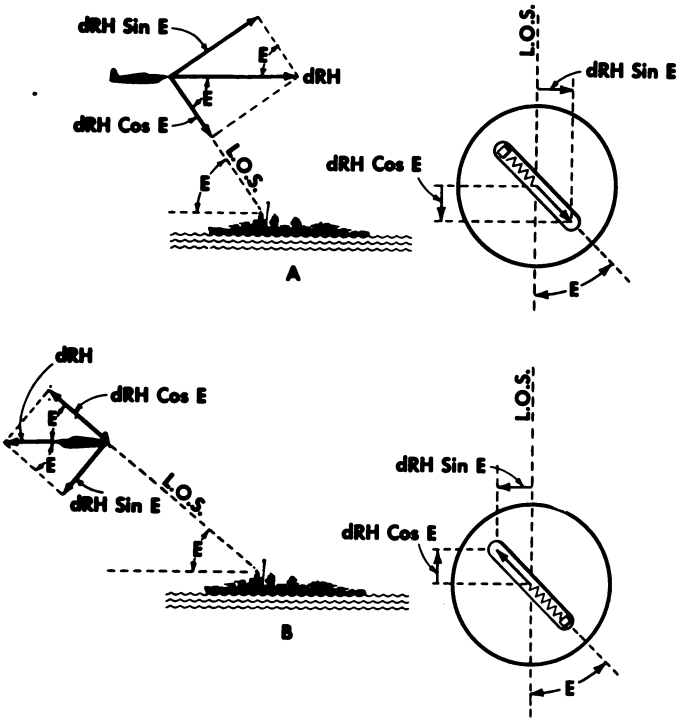


Figure 4–15.—Plus and minus components.

the same in each case. Notice in both figures how the screw-type component solver has resolved these negative and positive speeds into two components.

The method of locating the zero position of the speed pin is similar to that of the cam-type component solver. In this case the vector gear revolves only through 90° since target elevation can vary only from 0° to 90°. Rotation of the vector gear should produce no movement of either output slide when the speed pin is on zero.

The zero position of the vector gear is located in much the same way as with the cam-type component solver. But remember—even though you have located the zero position of the vector gear, it may be 180° out of adjustment. Thus,

Digitized by Google

s you crank in positive values of speed, the output rack may ıove in a negative direction.

Adjusting the Screw-Type Component Solver

Before you adjust a screw-type component solver, consult ıe OP. It will tell you how to check the movement of the ıtput slides. Here's one example: With the *E* dial set on ero, and target speed changed from zero to 400 knots, the sine rack should move toward the top of the component olver, and there should be no output on the sine slide.

In other words, the OP will immediately tell you whether ıe adjustment is correct or not. Always consult the OP nd perform your adjustments accurately.

THE OFFSET-PIN COMPONENT SOLVER

Up to this point in your study of fire control basic mechnisms, you have found that there are a lot of different ways f skinning a cat. Each has certain advantages. Consider ıe number of different multipliers we have studied. They ll multiply, but, for a particular problem, the sector-type ıay have distinct advantages over the rack-type.

The same thing is true with component solvers. The screwype component solver can have both positive and negative ıputs, but on the other hand, the screw has a tendency to ear and develop lost motion through long usage. A camype component solver will outwear the screw-type since the am follower is a roller bearing which reduces friction to a ıinimum.

For this reason, the OFFSET-PIN COMPONENT SOLVER, shown ı figure 4–16, is often used when both positive and negative peed inputs are required, and when the component solver is ubject to continually changing inputs.

The offset-pin component solver has an ordinary constant ead cam. In order to use half of the cam-follower motion s positive and half as negative, the pin which moves the acks is OFFSET half way between the center and edge of the am as shown in figure 4–17.

Digitized by Google

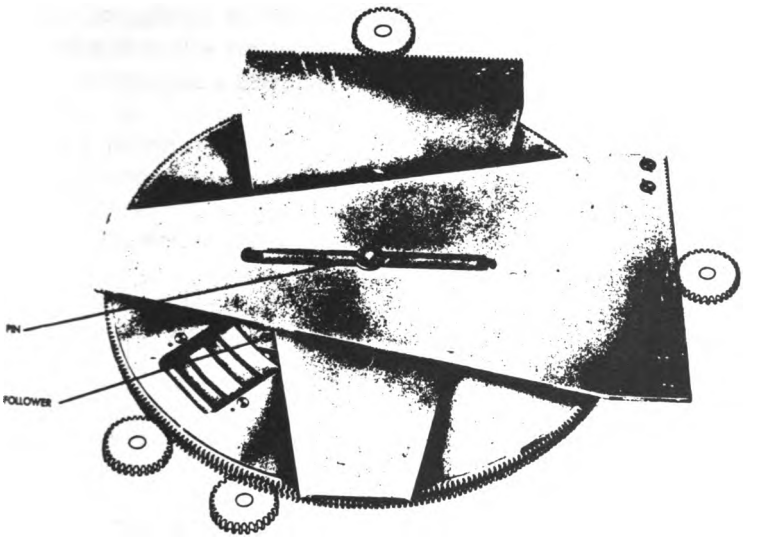


Figure 4–16.—Offset-pin component solver.

The follower and the pin are mounted on opposite ends of a steel plate which slides in the vector slot. Thus, although the cam follower travels only from the center to the edge of the cam, the pin travels half of this distance on each side of the offset center. So, for any one position of the vector gear, the outputs on the racks can be positive or negative.

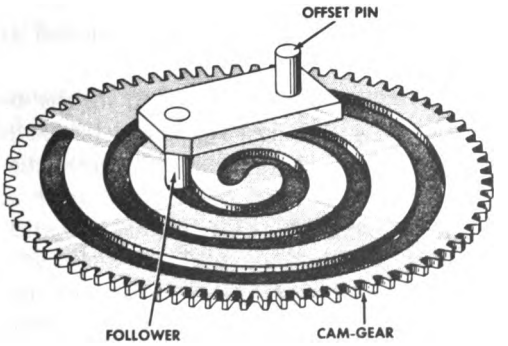


Figure 4–17.—Offset-pin.

Digitized by Google

Let's look at the operation as shown in figure 4–18. Notice in figure 4–18A that the component solver is solving positive values. When the cam is turned one way the follower moves from its zero position toward the edge of the cam. And when the cam is reversed, the follower moves from the edge toward the center. In the case shown here,

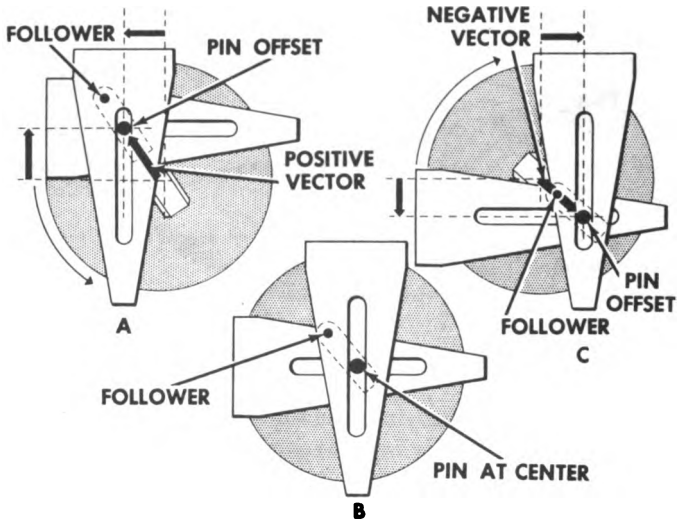


Figure 4–18.—Plus and minus values.

the outward motion of the follower is positive. However, this won't always be the case. Notice that at the maximum positive position the follower is at the outer end of the cam groove.

Figure 4–18B shows the zero position of the component solver. As usual, you will find the speed pin at the center of the component solver. When the pin is over the center of th solver, the racks are at zero, but the follower in the cam groove is about half way between the center and the edge of the cam.

In figure 4–18C the speed input to the cam is negative; consequently, the vector is negative and the racks have moved in the OPPOSITE direction.

Digitized by Google

At the maximum negative position the cam follower has moved to the inner end of the cam groove.

The offset-pin component solver is about the same as the screw-type component solver. In fact, with a few changes in gear ratios they could replace each other and work just as well. Speed inputs can be either positive or negative, whereas vector-gear inputs are usually POSITIVE only, as in the case of target elevation where they vary from 0° to 90°.

You can immediately see the need for a compensating differential on the speed input to allow for changes in the vector gear, which would otherwise affect the speed-pin position. The differential arrangement is identical with that used in the cam-type component solver.

You should have no trouble with the adjustments of this component solver—the same theory applies for all component solvers. Just remember to make them accurately.

Since either end of the vector slot can be used to indicate positive values, always consult the OP. It will tell you the correct direction of the output movement of the slides for positive values.

THE VECTOR SOLVER

By now you should have the theory of component solvers down pat. Actually there isn't much to them once you understand their construction and theory. So let's look at a component solver in reverse—in other words, a VECTOR SOLVER.

The component solver resolves a vector, representing course and speed, into two components at right angles to each other. The vector solver does just the opposite. The inputs to a vector solver are the two right-angle components of a vector. The vector solver uses these two components to solve for the VECTOR. Its outputs are COURSE and SPEED.

Why do we need a vector solver? Suppose you were tracking a target at night. You would have to know the target's course and speed before you could open fire with

Digitized by Google

any hope of knocking it for a loop. It's a cinch the target won't reveal what course it is flying. It can be done with a vector solver.

Your computer or rangekeeper figures target course from changes in target bearing and range as you track the target with the director and radar. The director transmits the continuously changing range and bearing of the target to the plotting room. The computer compares these quantities with the last transmitted position of the target. The computer then calculates how much true bearing of the target is changing per second, and how much its range is changing per second. In other words, the computer calculates a range component and a deflection component of target movement relative to true north.

These two components of target movement relative to true north are called the target's EAST-WEST and NORTH-SOUTH movements. They serve as inputs to the vector solver, whose outputs are target course and speed.

Figure 4–19 shows an exploded view of the working parts of a vector solver. The construction of the racks is similar

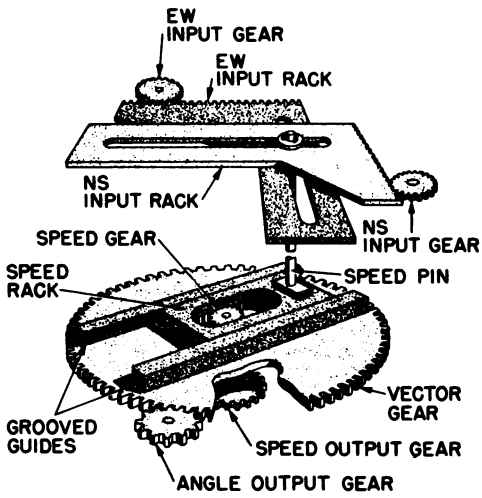


Figure 4–19.—Vector solver.

Digitized by Google

to that of a cam-type component solver. These racks move on bearings in machined guide rails. They move at right angles to each other.

A speed pin comes up through the slots in these two racks so that the position of the pin changes with every input movement of one or both racks. The other end of the speed pin is anchored to a speed rack. The SPEED RACK slides between the two grooved guides (fastened to the vector gear) whenever the SPEED PIN moves across the vector gear.

The speed gear at the center of the vector gear meshes with the speed rack. Movement of the speed rack along its guides rotates the speed gear. The speed gear turns an output gear below the vector plate.

Notice that the movement of the input racks and the speed pin also causes the vector gear to turn. The vector gear then turns the angle output gear.

To sum it up, the vector solver works like this: The inputs on the racks move the pin; movement of the pin changes the position of the vector and speed gears; and the position of the vector gear and speed gear represents TARGET COURSE and TARGET SPEED.

The theoretical solution of the vector solver is shown in figure 4–20. Notice that its two inputs are the north-south

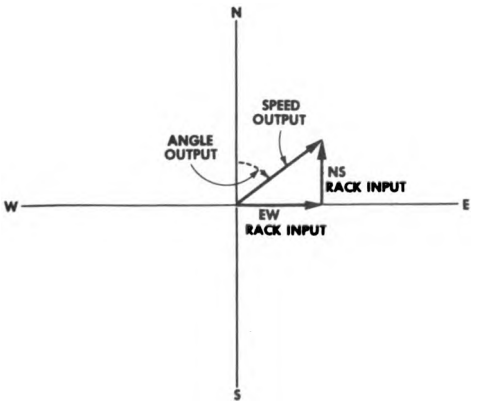


Figure 4–20.—Composition.

Digitized by Google

and east-west components of target-motion. The output is a vector whose length is the speed of the target, and whose angle is target course relative to true north.

Adjustment of the Vector Solver

The adjustment of a vector solver isn't much different from that of a component solver. In fact, it is usually adjusted as though it were a component solver. You use the outputs (target course and speed) as inputs—then you check for movement of the input slides.

The OP on any equipment using a vector solver will cover the adjustment procedure in complete detail. Its adjustment usually depends on the particular construction of your range-keeper or computer.

Briefly, though, if target speed is on zero, rotation of the target-course output should produce no movement of either input slide. If target course is on zero, movement of target speed should produce no movement of the east-west rack. If target course is on 90° or 270°, movement of target speed should produce no movement of the north-south rack.

You can see in figure 4–19 that a compensating differential is necessary because the vector-solver action is similar to that of the component solver. That is, outputs at the speed gear are always target-speed PLUS target-course, whereas the output of the vector gear is target course only.

Strengthening the Vector-Solver Outputs

The outputs of a vector solver are usually very weak mechanical signals. If a lot of output gearing is added, which is often the case, strain is placed on the vector solver, causing the inputs to SLIP. Consequently, you will invariably find that the outputs of a vector solver are strengthened with SERVO MOTORS (small electric follow-up motors). One motor strengthens the speed output and another strengthens the target-angle output. Figure 4–21 shows a simplified drawing of how this is done.

Notice the shaded schematic diagrams of the servo motors

Digitized by Google

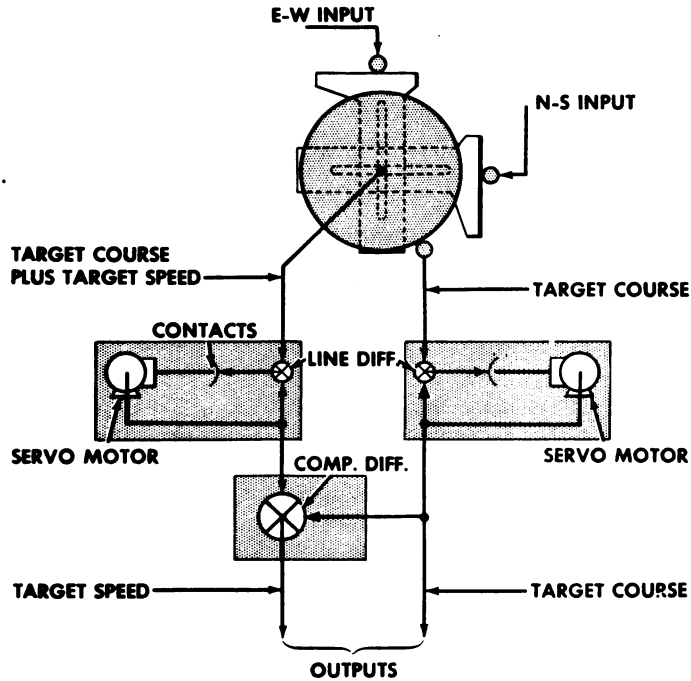


Figure 4–21.—The vector-solver outputs are strengthened by servo motors.

shown in figure 4–21. The weak vector-solver outputs drive into the side of a differential in either line. Then the spider positions a set of electrical contacts to energize the motor from the electrical supply (not shown in the figure). As these motors drive the output shafts connecting with the compensating differential, they also drive into the lower sides of the line differentials. Then the spiders turn in the opposite direction to open the servo motor's contacts. Thus the motors stop when the differentials sides have turned equal amounts.

Summing up, the outputs of the vector solver are strengthened by the servo follow-up motors. The compensating differential then subtracts the effect of target course on target speed, and the outputs become corrected TARGET COURSE and TARGET SPEED.

Digitized by Google

QUIZ

Select the answer (*a*, *b*, *c*, or *d*) which BEST completes the statement or answers the question.

1. The input to the vector gear of the cam-type component solver is the
   (*a*) target's course.
   (*b*) ship's movement relative to the line of sight.
   (*c*) ship's speed.
   (*d*) ship's course.

2. In what plane is relative target bearing always measured?
   (*a*) Horizontal.
   (*b*) Vertical.
   (*c*) Either horizontal or vertical.
   (*d*) Either horizontal or vertical, if proper adjustment is made.

3. If a ship is steaming directly toward or away from the target, what is the deflection component?
   (*a*) Twice the ship's speed.
   (*b*) The same as the ship's speed.
   (*c*) Zero.
   (*d*) None of the above.

4. In component solvers, changes in ship's course do NOT affect the ship's speed because of the
   (*a*) compensating differential.
   (*b*) precision-built input gears.
   (*c*) precision-built output gears.
   (*d*) rack guide rollers.

5. In what order should a cam-type component solver be adjusted if the angle-input adjusting coupling is located between the compensating differential and the solver?
   (*a*) Angle input BEFORE speed input.
   (*b*) Speed input BEFORE angle input.
   (*c*) Simultaneously.
   (*d*) No difference.

6. In what order should a cam-type component solver be adjusted if the angle-input adjusting coupling is NOT located between the compensating differential and the solver?
   (*a*) Angle input BEFORE speed input.
   (b) Speed input BEFORE angle input.
   (*c*) Simultaneously.
   (*d*) No difference.

Digitized by Google

7. The speed-gear adjustment of the cam-type component solver is PROPERLY adjusted when
   (*a*) it is at 0° or 180°.
   (*b*) the compensating differential no longer rotates.
   (*c*) no movement occurs on either slide when the angle gear is rotated.
   (*d*) the angle gear is set at 360°.

8. Which of the following is a component solver which can resolve both positive and negative target vectors?
   (*a*) Compensating.
   (*b*) Cam.
   (*c*) Rack.
   (*d*) Screw.

9. Which of the following is the MAIN DISADVANTAGE of the screw-type component solver?
   (*a*) The screw loses motion through long usage.
   (*b*) It cannot resolve both positive and negative inputs.
   (*c*) It has excessive friction.
   (*d*) It is too difficult to adjust.

10. The offset-pin component solver is MOST like the
   (*a*) cam-type component solver.
   (*b*) screw-type component solver.
   (*c*) vector-type component solver.
   (*d*) double-cam component solver.

11. The outputs of a vector solver are
   (*a*) range and bearing.
   (*b*) range and gun-train angle.
   (*c*) linear and angular velocity.
   (*d*) course and speed.

12. A vector solver is adjusted by
   (*a*) using the outputs as inputs and checking for movement of the input slides.
   (*b*) putting it on the zero position and checking with a dial indicator.
   (*c*) setting the angle at 360°.
   (*d*) none of the above.

13. The output of the angle gear of a vector solver is
   (*a*) target speed only.
   (*b*) target course only.
   (*c*) both target course and target speed.
   (*d*) none of the above.

Digitized by Google

14. The outputs of a vector solver are strengthened by
    (*a*) a compensating differential.
    (*b*) an additional gear.
    (*c*) output shafts.
    (*d*) small electric follow-up motors.

Digitized by Google

CHAPTER 5

MECHANICAL INTEGRATORS

PROCESS OF INTEGRATION

In previous chapters you learned that component solvers can be used to resolve the motion of own ship and target into two components: a range-rate component, and a deflection-rate component. You also discovered, from your study of the vector solver, that it is possible to calculate a target's course and speed, and changes in range, from movements of the director while tracking the target. In this chapter you will learn how the integrator helps solve the fire control problem.

One integrator makes it possible to "keep" the range to the target in the time interval between rangefinder ranges; another enables the computer to solve target course and speed, even though the director-operator's view of the target is momentarily obscured. These are only two applications of the integrator, but you will learn many more during your fire control career.

An integrator may be mechanical or electrical; but no matter how it is built, its basic purpose is the same. It adds up small changes to give you the total change. For example, it adds up small changes in target movement to give you the total change in range since the last rangefinder range. This process is called integration.

Let's take range rate as an example. You know that range rate means the relative movement of own ship and

Digitized by Google

target along the line of sight. It can be expressed a number of different ways—miles per hour, yards per minute, yards per second, or even yards per hundredth of a second.

Suppose you knew that the range rate of a surface target moving directly toward your ship was 10 yards per second. If someone asked you how far it moved in ten seconds you would say 100 yards. You simply multiplied rate by time to find the target's change in range.

Range rate multiplied by time=change in range, or 10 yards/second×10 seconds=100 yards change in range.

Looking at it another way you could say you performed a simple INTEGRATION. You actually added all the small changes (yards per second) to give you the total change (change in range).

Suppose you were tracking an attacking torpedo boat that was twisting and dodging like a broken-field runner on a football field. Every time the target changed course, its range rate would also change. What would you do then?

You could solve the change in range by integration. The target component solver would give you the target's range rate for every instant of time, since it is continuously solving the vector of target course and speed. You could take these changing range rates and multiply each one by the time it took the target to steer that particular course, and add the results. The total would be the total change in range—the sum of all the little parts. The basic integrator does this for you.

Basic Integrator

Figure 5–1 shows you a simple mechanism which will solve the problem of the torpedo boat's change in range. That is, it will continuously multiply the instantaneous values of range rate by time, and continuously add up all these small changes to give you total change in range.

Study its construction. It is like a variable gear ratio. The disk is rotated at a constant speed. The disk, through friction, drives the wheel which rests on its surface. Notice

Digitized by Google

that the distance of the wheel from the center of the disk can be varied. When the output wheel is near the outside of the disk, it will rotate faster than when it is near the center. When the wheel is at the center of the disk, its output is zero.

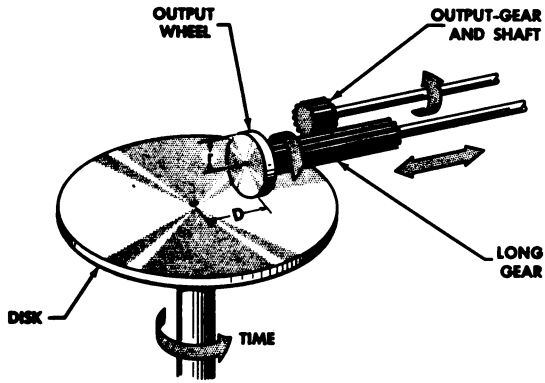


Figure 5–1.—Basic integrator.

You can see that we have a variable gear ratio. The ratio is the distance of the wheel from the center, divided by the radius of the output wheel.

$$\frac{D}{r} = \text{ratio}.$$

You will remember that the output of a pair of gears is equal to the input times the gear ratio. Applying this formula to figure 5–1 you have,

$$\text{output} = \text{input} \times \frac{D}{r}.$$

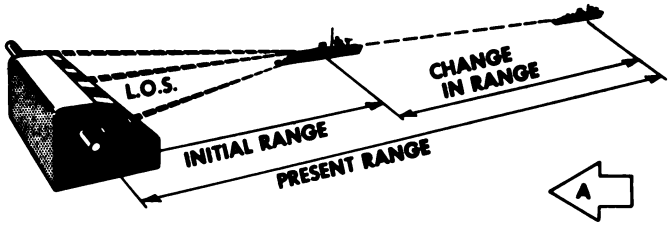
Since the radius r of the small wheel is a constant, you can compensate for it by selecting the proper output gearing—then ignoring the constant r:

$$\text{output} = \text{input} \times D$$

or, change of range = time × range rate.

Figure 5–2A illustrates the problem which the integrator solves. The target ship is cruising away from own ship, increasing range at a certain range rate. As long as target

Digitized by Google



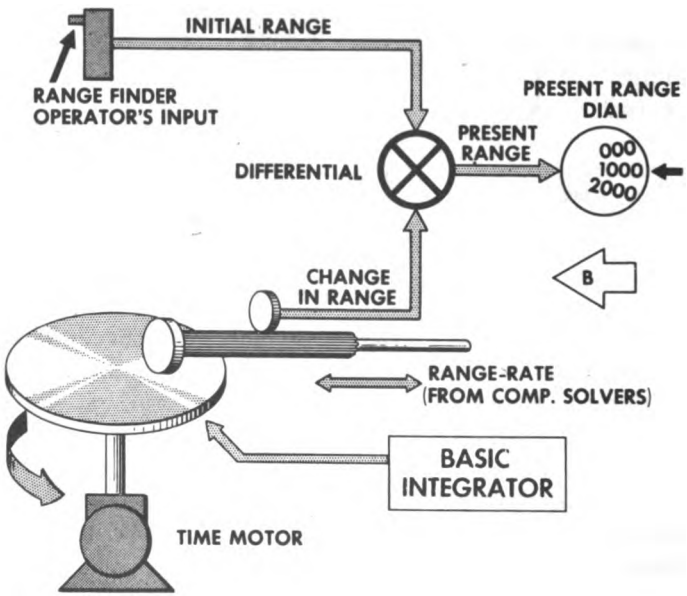


Figure 5–2.—The integrator keeps the range.

speed is constant, range rate remains constant. Range rate is computed by the own ship and target component solvers. The distance that the basic integrator output wheel is positioned away from the center of the disk is proportional to RANGE RATE (see fig. 5–2B).

The integrator keeps range for you by computing total CHANGE IN RANGE. This is the integrator output.

Going back to figure 5–2B again, notice how the range-

Digitized by Google

finder operator can introduce initial range through the differential to set the present-range dial. In the intervals between the rangefinder operator's ranges, the integrator keeps on turning out changes in range. These are added by the differential to initial range. The result is continuous and accurate present range.

Now you can see one important reason for adjusting your component solvers accurately. The range-rate output of your own ship and target component solvers continually positions the wheel with respect to the center of the integrator. If your component solvers aren't accurate, range rate will be in error. If range rate isn't correct, the output of your integrator will be in error. If change of range is wrong, present range is wrong—you must have accurate ranges to get hits.

The integrator shown in figure 5–2 isn't too satisfactory in fire control equipment for several reasons. One reason is

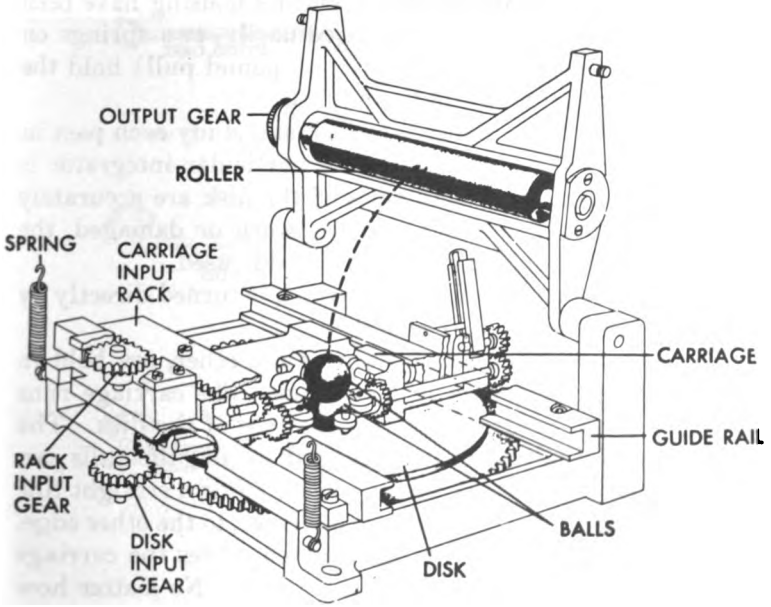


Figure 5–3.—Ball-and-roller-type integrator.

Digitized by Google

this: every time the radial position of the wheel is changed it drags on the integrator disk, which tends to slow down the constant speed input. As a result of this and other inaccuracies, an integrator of the type shown in figure 5–3 is actually used in modern equipment.

AN ACTUAL INTEGRATOR

The modern integrator shown in figure 5–3 is an accurately machined mechanism. It has been designed to overcome all the errors and difficulties of the basic integrator. For example, the difficulty of pushing the wheel across the integrator disk has been overcome by replacing the wheel with two balls and an output roller. Two balls are used because it makes it easier to change the position of the carriage. These balls move back and forth across the face of the integrator in a carriage, and at the same time transfer rotation of the disk to the output roller.

In figure 5–3 the output roller and its housing have been lifted to show the mechanism. Ordinarily, two springs on the housing (each of which exerts a 9-pound pull) hold the output roller against the balls and disk.

Let's start with the integrator disk and study each part in detail. The integrator disk in this particular integrator is 5 inches in diameter. Both sides of the disk are accurately ground. Thus, if one face becomes worn or damaged, the disk can be turned over and the other side used.

The disk is mounted on a gear, which is turned directly by an input gear that meshes with it.

The two steel balls, one on top of the other, are held in position by guide rollers in a carriage. The carriage runs along a pair of guide rails across the face of the disk. The carriage and guide rails are arranged so that the balls can be positioned by the carriage anywhere along a straight line from one edge of the disk, across the center, to the other edge.

Notice the carriage input gear which moves the carriage and balls across the face of the integrator. No matter how the integrator is used, the carriage input is always the RATE

Digitized by Google

INPUT. It corresponds to the range-rate input in your basic integrator.

The operation of the ball-and-roller-type integrator is simple. The disk, which is driven by the input gear, drives the balls in the carriage. In turn, these balls transfer rotation of the disk to the output roller and output gear. The rate of rotation of the output roller is always proportional to the speed of the integrator disk and to the position of the carriage.

Integrator Action

You will remember from your study of range rates and component solvers that it is possible to have both positive and negative range rates. (The target can either be approaching or going away from own ship.) Well, the integrator can handle positive or negative rates with equal ability.

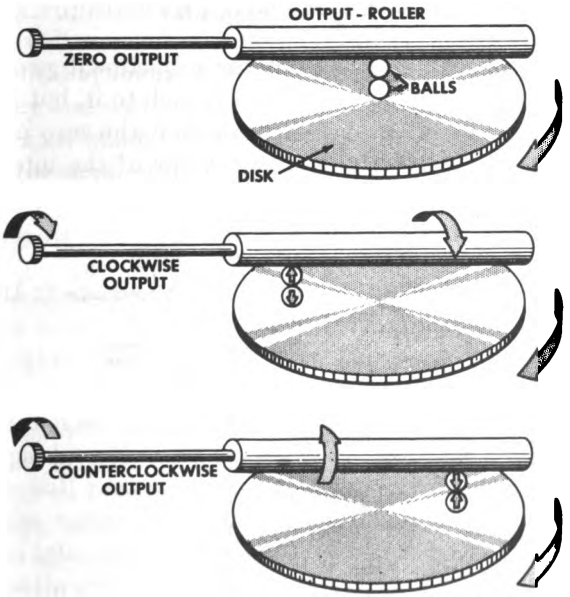


Figure 5–4.—Integrator action.

Digitized by Google

A study of figure 5–4 will show you why. Remember that the carriage can be positioned anywhere along a straight line from one edge of the disk, across the center, to the other edge. If the carriage and balls are in the center of the disk, the roller output is zero. While if the carriage is positioned to the left of the disk center, the rotation of the output roller is clockwise. Moving the carriage to the right of center reverses the output roller; therefore, it rotates counterclockwise.

To boil it down, all you have to do is assign negative values to clockwise rotation and positive values to counterclockwise rotation of the output roller. Then your integrator can handle positive or negative rates. Of course, the assignment of positive and negative values to the output of the roller depends on how the integrator is installed, just as with the screw-type multiplier.

Adjusting the Integrator

You have probably doped out the adjustment procedure for the integrator by now; there isn't much to it, but it must be accurate. The integrator carriage is at the zero position when the balls are exactly over the center of the integrator disk. In other words, if you set the rate input to the inte-

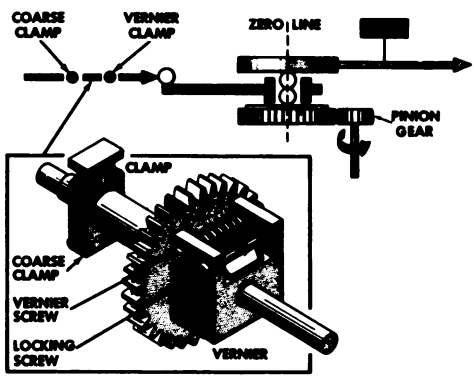


Figure 5–5.—Adjusting the integrator carriage.

Digitized by Google

grator on zero, the roller output should be zero. If it isn't, adjust the carriage until the roller output is zero.

There are usually two adjustments on the carriage input to the integrator; one is a clamp adjustment and the other is a vernier adjustment, as shown in figure 5–5.

When zeroing the integrator, your first step is the course adjustment. With the rate input on zero, loosen the clamp and rotate the carriage input until the roller output is close to zero. Then tighten the clamp.

Next comes the zero or precision adjustment. Loosen the locking screw on the vernier and adjust the vernier screw until the carriage is in the exact center of the integrator disk. When the carriage is centered there is no movement of the output roller. Then tighten the vernier-locking screw.

There are many different uses for the integrator, and the adjustment procedure varies with each application. Always consult the OP on the rangekeeper or computer before making any adjustments.

You will encounter some integrators that have additional mechanical refinements which are designed to improve their accuracy and wearing qualities. But no matter what design changes are made, the basic principle of the integrator remains the same—rate multiplied by time equals change.

COMPONENT INTEGRATOR

With the advent of the airplane and radar it became necessary to be able to solve a target's course and speed, even at night when the target was invisible, and do it in a hurry. That's why you have vector solvers to resolve NORTH-SOUTH and EAST-WEST components of target motion into target course and speed.

You will remember from your study of the vector solver that the vector solver resolves these components of target motion into target course and speed. The vector solver had to have these two components of target motion before it could perform its calculations.

Digitized by Google

That is where the component integrator enters the fire control problem. The component integrator calculates the north-south and east-west movements of the target from target bearing, and from changes in bearing and range. The outputs of the component integrator positions the racks of the vector solver. The vector solver then solves for target course and speed as you learned in the last chapter.

Figure 5–6 shows the flow from the component integrators to the vector solvers. Study the schematic diagram carefully. Notice the familiar servo motors and the compensating differential. You'll see them used in many places.

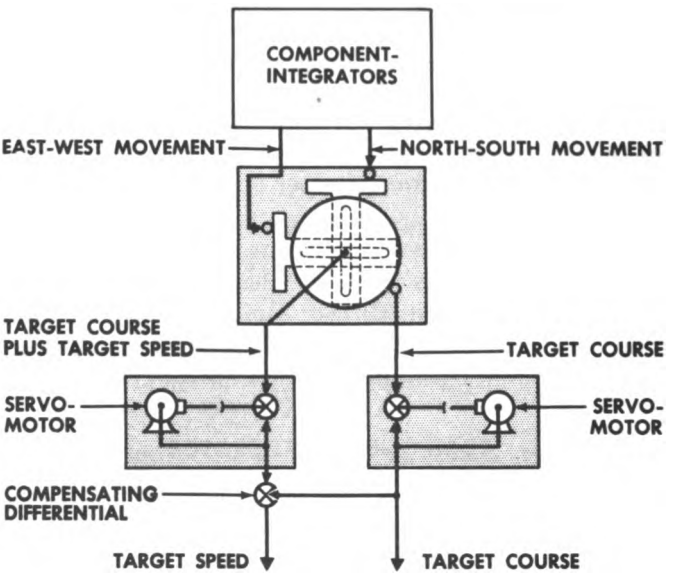


Figure 5–6.—Flow of information from the component integrator.

Let's use the familier quantity change of range as an example to illustrate the method of calculating target speed from changes in bearing and range.

Imagine that you have picked up a target by means of radar at night. Since the target is invisible you estimate a target course and speed. To make it easy, let's assume that the target is moving up a narrow channel. You know

Digitized by Google

that it is coming directly toward own ship. That leaves only target speed to be determined.

You set the known target course and estimated target speed on the target component solver in the rangekeeper. The range-rate output of the target component solver positions the carriage of the range-rate integrator. The integrator starts generating changes in range.

After one minute the change in range from the integrator reads 100 yards, but the difference in radar ranges is only 50 yards. This means that there is a 50-yard error in GENERATED CHANGE OF RANGE after the first minute. Since the radar ranges are assumed to be accurate, it means that you have used the wrong estimate of target speed; therefore, you reduce your estimate of target speed by one-half. This decreases range rate, which decreases generated change in range.

At the end of the next minute (two minutes have passed), the integrator output reads 50 yards change in target range. Meanwhile, the radar indicates that the target has actually changed its range by 50 yards. Now you can say that the generated changes in range from the computer agree with the observed changes in range. You found the corrected target speed by comparing generated and observed changes in range, and by using the difference to estimate a new target speed.

The above was an easy problem. The target wasn't moving very fast, and you had to worry only about target speed. Then, too, you had plenty of time to solve target speed before the target came within range of your guns.

Like many stories, this one doesn't agree with real life. Actually, in the case of an airplane, the target would be moving several hundred miles per hour, and you would have only a few seconds to solve target course and speed before opening fire. Then, too, you would have to solve its movement in three coordinates. Its bearing, elevation, and range are constantly changing.

You couldn't compare differences between generated and

Digitized by Google

observed bearings, elevation, and range simultaneously. Even if you could watch all three dials, you wouldn't know whether target course or target speed was correct. So, as in other computations in the fire control problem, you substitute a mechanical computing device. In this case, it is a component integrator.

The primary purpose of a component integrator is to resolve a vector into two components. The length of the vector represents differences between generated and observed changes of target movement. The vector angle is the bearing of the target motion, relative to true north.

In other words, component integrators use differences between generated and observed changes of target movement and target position to compute north-south and east-west changes in target movement. The vector solver then resolves these two movements into target course and target speed. Go back and study figure 5–6 again and make sure you understand the flow of information.

Component Integrator Construction

Examine the construction of the component integrator as shown in the cutaway view in figure 5–7. Basically, the integrator consists of a steel ball supported by five rollers. Two of these rollers are guide rollers, two are output rollers, and one is an input roller. The input roller is driven by the LENGTH of the vector (at the speed input), and its spin axis is changed by the ANGLE of the vector (angle input).

The bottom or input roller drives the ball which in turn drives the two output rollers. These two output rollers are mounted at right angles to each other. The function of the two guide rollers is to hold the ball in place. These guide rollers are held in place by spring tension.

Notice the two inputs to the component integrator. The speed-shaft's rate of rotation, which is proportional to the length of the vector, drives the input roller through the pair of bevel gears. The angle gear changes the spin axis of the input roller relative to the two output rollers.

Digitized by Google

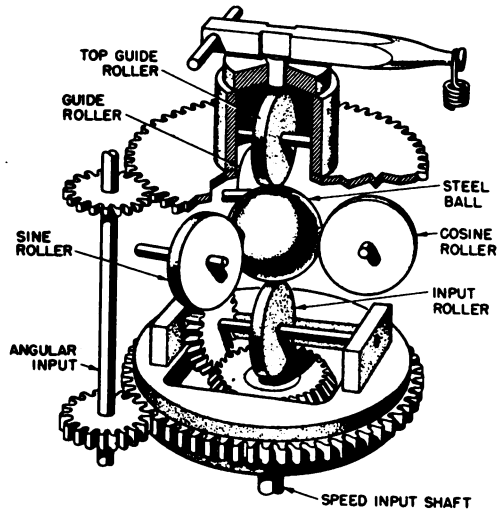


Figure 5–7.—Component integrator.

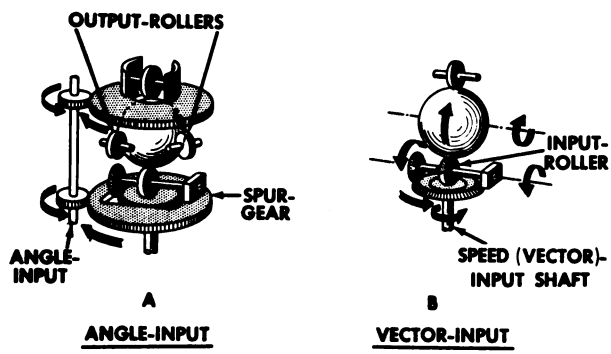


Figure 5–8.—Angle and vector input.

Figure 5–8A shows how the angle input turns the axis of rotation of the driving roller. The angle input drives the large spur gear on which the input roller shaft is mounted. When the spur gear is rotated, the angular position of the input roller varies in relation to the two output rollers.

At the same time, the angle input turns the large upper spur gear so that the plane of rotation of the top guide roller

Digitized by Google

is always the same as the bottom input roller. Since both the top and bottom rollers lie in the same plane of rotation, any rotation of the ball will also be in this same plane.

The vector or speed input drives the input roller and ball through the pair of bevel gears. Notice in figure 5–8B that the plane of rotation of the ball is always the same as the input roller and the top guide roller. To express it another way, the spin axis of the ball is always parallel to the spin axis of the input and top guide rollers.

Component Integrator Action

Since the two output rollers are driven by the rotation of the ball, their speed of rotation is proportional to the angle between the axis of spin of the ball and their own axes of rotation. Figure 5–9 illustrates this relationship.

Study these three views—they can tell you more than a thousand words. Notice that when the spin axis of either roller is located 90 degrees from the spin axis of the ball the output is zero. Also, if either roller is placed so that its spin axis is parallel to the spin axis of the ball, as shown in the lower right hand view of figure 5–9, the roller output is maximum. Intermediate positions of the roller produce corresponding speeds.

The side views in figure 5–9 show you the path of one of the output rollers about the spin axis of the ball. As the axis of the ball moves toward a right angle with the axis of the output roller, the length of the roller path decreases. In turn, the speed of the output roller decreases.

This relationship between the spin axes of the ball and rollers can be expressed as the SINE and COSINE of the angle. In fact, like the component solver, that is where the component integrator gets its name. It RESOLVES a VECTOR into two outputs that are proportional to the sine and cosine of the angle-gear input.

Be sure to distinguish between the component solver and the component integrator. The length of the vector in a component solver is proportional to speed and can be represented

Digitized by Google

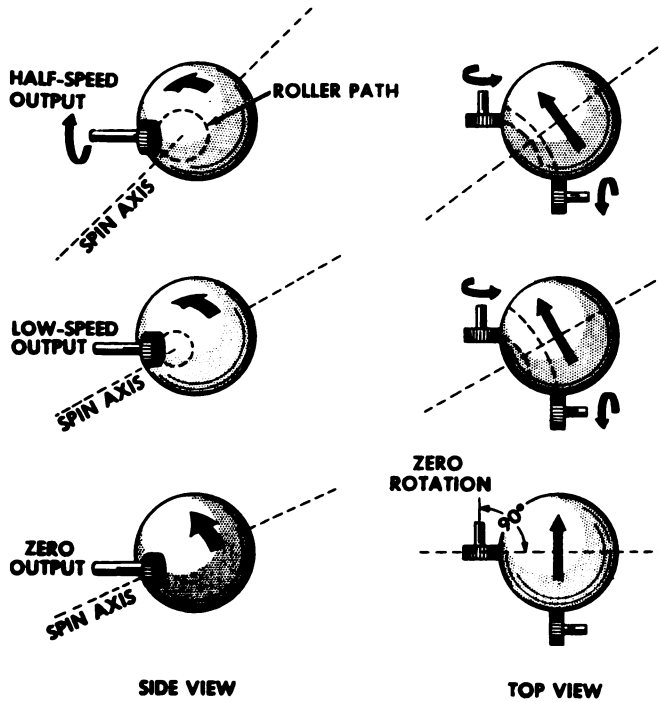


Figure 5–9.—Ball-and-roller action.

by the distance of a pin from the center of the component solver. On the other hand, the length of the vector in the component integrator is proportional to the DIFFERENCE between generated and observed changes of bearing, elevation, or range.

Both generated and observed changes are continuously varying quantities, and are represented by the RATE OF ROTATION of shafts. Therefore any difference between the two is a continuously changing quantity: That is, a continuous rotation of a shaft whose rate of rotation is proportional to the difference. This rate of rotation of the speed-input shaft is the VECTOR INPUT of the component integrator.

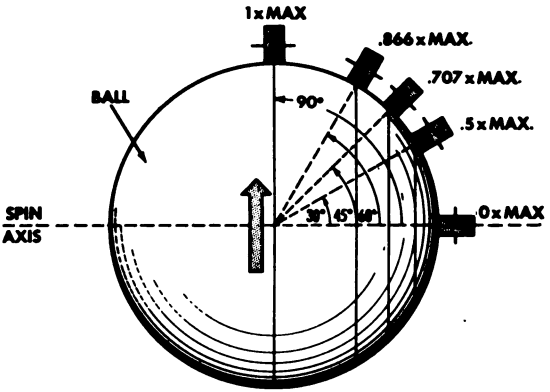
The component integrator then takes this vector input

Digitized by Google

and continuously RESOLVES and INTEGRATES it into two right-angle components which are NORTH-SOUTH and EAST-WEST CHANGES in target movement.

Now you can see why the mechanism is called a component integrator. The outputs are not only right-angle components of the vector and angle inputs, but at any instant the total rotation of an output shaft is proportional to the target movement along that component.

In other words, the little changes of the output shafts are continually being added to give total changes which are north-south and east-west movements of the target.



SINE 90° = 1
SINE 60° = .866
SINE 45° = .707
SINE 30° = .5
SINE 0° = 0

Figure 5–10.—Resolving the vector.

Study figure 5–10. It shows the relationship of one of the output rollers to the spin axis of the ball. Notice how the output of the roller varies as it occupies different angular positions relative to the spin axis of the ball. In this case, the output of the roller varies as the sine of the angle. Another roller placed 90° away from the output roller would vary as the cosine of the angle.

The action of the component integrator having two output rollers is shown in figure 5–11. The rate of rotation of

Digitized by Google

one output roller varies as the value of the input multiplied by the sine of the angle, while the output of the other roller varies as the input multiplied by the cosine of the angle. If you carefully study the diagram in figure 5–11 you won't have any difficulty in understanding the action of a component integrator.

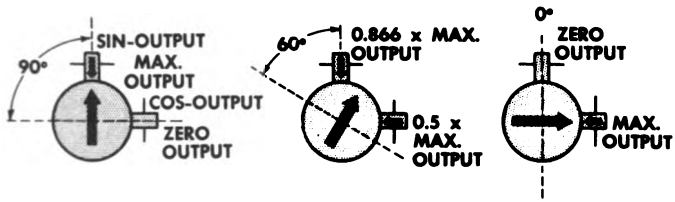


Figure 5–11.—Action with two rollers.

The value of the sine of 90° is one. Thus, when the axis of the sine roller is parallel to the spin axis, its output is maximum. Since the cosine of 90° is zero, the output of the cosine roller is zero when the angle is 90°.

You can see from figure 5–11 that either roller could be called the sine roller. It depends on whether you measure the angle from the vertical or horizontal. You will notice in figure 5–11 that the angle was measured from the vertical, which made the top roller the sine roller. Suppose you measured the angle of the spin axis of the ball relative to the side roller—the side roller would become the sine roller and the top roller would be the cosine roller.

Adjusting the Component Integrator

Whenever you look at a component integrator in a computer, always remember that the output of the rollers depends on how the mechanism was installed—so check the OP. It will tell you which output is the cosine output and which is the sine output.

Once you know the outputs, the adjustment is easy. With the angle gear set on zero, there shouldn't be any output at the sine shaft. Likewise, if you set the angle gear at the

Digitized by Google

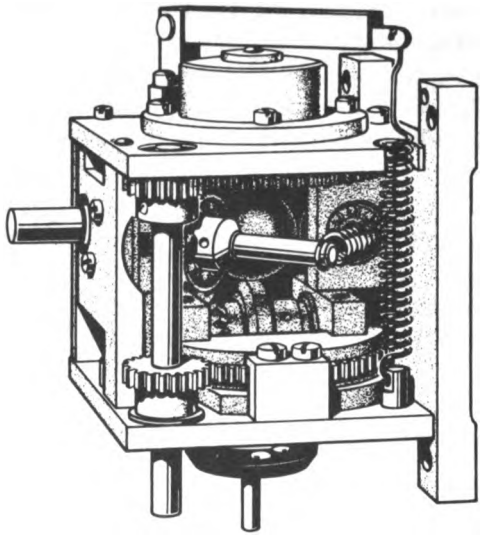


Figure 5–12.—The component integrator.

90° position, there shouldn't be any output at the cosine-shaft. Be sure and carefully check the OP. It will tell you exactly how the adjustments should be made.

Figure 5–12 is a drawing of a complete component integrator. You can see that it is a compact little mechanism. But remember that important things often come in small packages. Without the component integrator it would be impossible to solve the fire control problem quickly and accurately, especially at night or whenever the visibility is poor.

You will learn more about the use of the component integrator when you have studied the air problem in another Navy Training Course.

When you study the air problem and the application of the component integrator, just remember what it does: it resolves a vector (whose length represents the difference between generated and observed changes of target movement) into two components which are at right angles to each other.

Digitized by Google

QUIZ

Select the answer (*a*, *b*, *c*, or *d*) which BEST completes the statement or answers the question.

1. The basic purpose of the integrator is to
   (*a*) keep track of time intervals.
   (*b*) multiply a quantity by a rate.
   (*c*) resolve two quantities into right angle components.
   (*d*) continuously add small changes to give the total change.

2. Range rate is expressed in
   (*a*) yards per second.
   (*b*) yards.
   (*c*) nautical miles
   (*d*) foot seconds.

3. When range rate is multiplied by time, you get
   (*a*) change in range.
   (*b*) present range.
   (*c*) per cent of change in range.
   (*d*) knots.

4. When the change in range output of an integrator is added to initial range, you get
   (*a*) range to future target position.
   (*b*) continuous present range.
   (*c*) range correction.
   (*d*) range error.

5. The two inputs to a range integrator are
   (*a*) initial range and range rate.
   (*b*) present range and range rate.
   (*c*) time and range rate.
   (*d*) time and present range.

6. The output of the range integrator is proportional to
   (*a*) total range prediction.
   (*b*) range rate.
   (*c*) present range.
   (*d*) total change in range.

7. The input to the disk of a range integrator is
   (*a*) initial range.
   (*b*) time.
   (*c*) present range.
   (*d*) range rate.

Digitized by Google

8. When the balls of an integrator are exactly over the center of the disk, the input to the carriage is
   (*a*) zero.
   (*b*) maximum negative.
   (*c*) maximum positive.
   (*d*) at one half maximum regardless of sign.
9. The output of an integrator appears at the
   (*a*) carriage.
   (*b*) roller.
   (*c*) balls.
   (*d*) disk.
10. As the carriage of an integrator positions the balls from one side of center to the other, the output roller
   (*a*) reverses for each turn of the disk.
   (*b*) keeps a fixed position.
   (*c*) reverses rotation.
   (*d*) continues to rotate at a constant speed.
11. When the range integrator is in accurate adjustment, the
   (*a*) output roller remains stationary when range rate is zero.
   (*b*) balls are at one edge of the disk when range rate is zero.
   (*c*) disk remains stationary when the zero point is reached.
   (*d*) output roller is running at maximum speed when range rate is zero.
12. In the component integrator, the position of the spin axis of the input roller is determined by the
   (*a*) angle input.
   (*b*) speed input.
   (*c*) vector input.
   (*d*) guide roller position.
13. In a properly adjusted component integrator, when the spin axis of the ball is parallel to the spin axis of one output roller, the speed of the OTHER output roller is at
   (*a*) zero.
   (*b*) one-quarter speed.
   (*c*) one-half speed.
   (*d*) full speed.

Digitized by Google

CHAPTER 6

FIRE CONTROL GYROSCOPES

WHERE GYROSCOPES ARE USED

At some time or another you have no doubt watched the gravity-defying antics of a rolling hoop, a spinning top, or a toy gyro without realizing that the properties displayed by these toys have virtually revolutionized naval gunnery and fire control.

The child's toy—the gyroscope—has grown up to become the "brains" of innumerable fire control and gunnery instruments. The gyroscope, in its different applications, not only stabilizes the fire control system, but it helps solve the fire control problem from the moment the target is sighted until the projectile hits the target—even the swift and accurate flight of the projectile depends on the stability of a spinning body.

Ask a torpedoman to show you the inside of a torpedo; you'll find a gyroscope at the controls. It steers the torpedo on a straight predetermined course.

Its applications are not confined to gunnery alone: Modern navigation depends on the accuracy of the gyro compass (or master compass), and the Italians built the huge luxury liner Conte Di Savoia around a gyro, which was designed to stabilize the whole ship against the roll and pitch caused by heavy seas.

Stability isn't the only property of a gyro however. Let's go back to the hoop that you used to roll in your boyhood days and examine it again.

Digitized by Google

Remember how you used to stand the hoop upright while you were learning to roll it? It fell over every time. But after a few tries you found that the trick was to start it rolling with a flick of the wrist. Then, instead of falling, it rolled along, upright, defying the laws of gravity. So you ran after it, propelling it with the batter, and it always stood upright as long as it was rolling.

Then how did you go about steering the hoop? If you wanted it to turn right, and you pushed the forward edge to the right, or the after edge to the left—the hoop would promptly fall over. But if you think back, that's not what you did at all. You pushed the TOP of the hoop to the right—and the hoop swung around as neatly as you please.

Evidently, when a hoop is spinning it behaves quite differently from the way it does when standing still. Any spinning object—a hoop, an engine flywheel, an airplane propeller, the tires on an auto, or a bullet from a rifled gun—has a trait called GYROSCOPIC ACTION.

There are two important peculiarities about the behavior of a gyroscope, and the action of a hoop illustrates both. The fact that a hoop stands upright when it spins is an example of GYROSCOPIC STABILITY. And the way it is steered is governed by the laws of PRECESSION.

Gyroscopic stability means simply that any revolving wheel will keep spinning in the same plane—that is, with its axle headed in the same direction in space—until some outside force moves it. The heavier the wheel and the faster it spins, the more firmly it tries to stay in the same plane of rotation. The force required to turn it out of that plane will be proportionally greater.

Actually, there's nothing mysterious about gyroscopic stability. It's just an example of one of Sir Isaac Newton's basic laws of motion—any moving body tends to continue moving in the same straight line and at the same velocity unless acted upon by some exterior force.

Digitized by Google

The force required to move the body out of that line is proportional to the body's momentum (its mass times its velocity). Each particle of material in the rim of a rotating wheel is trying at all times to move in a straight line. The structure of the wheel pulls them into a circular path, but they keep trying to stay as nearly in a straight line as possible. Consequently, the wheel keeps rotating in the same plane.

Most of the wheels with which you are acquainted are fastened so that they aren't always free to rotate in the plane they want to. An auto wheel is controlled by the steering apparatus. Normally, therefore, you don't notice the effects of gyroscopic stability, though the stability of the propeller sometimes causes trouble for high-powered airplanes.

But suppose you mount a wheel so that it is free to aline its axis (or axle) in any direction, like the one in figure 6–1A.

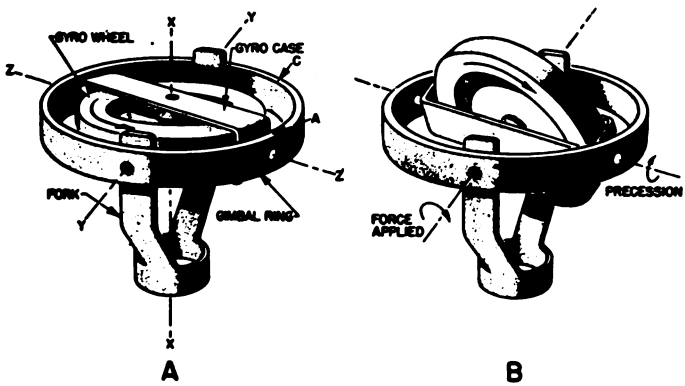


Figure 6–1.—How a gimbal mounted gyro is precessed.

The wheel rotates inside a flat loop called the GYRO CASE (the name is different for some applications). The gyro case encloses the entire wheel. Thus the wheel is free to rotate in any plane. The gyro case is pivoted in a ring—the GIMBAL RING—so that the axis of the gyro can swing forward and back. The gimbal ring itself turns on pivots connecting it to the FORK. This permits the gyro axis to tilt from side to side. This type of mounting is called a GIMBAL MOUNTING.

Digitized by Google

Regardless of how the fork is placed, the spinning gyro wheel is free to lie in any given plane. That's why it is called a FREE GYROSCOPE.

Gyroscopic stability shows up very plainly. Suppose you lined up the spinning gyro wheel so that its axle (x–x) headed toward the North Star. You could take hold of the fork and turn it, tilt it, or swing it any way you wished, and the gyro axle would continue to point toward the North Star.

PRECESSION

Now try something else. Push down on the gimbal ring at point A (fig. 6–1A) at the nearest end of the z-z axis. You expect the ring to tilt turning around the y-y axis, don't you?

But here's the surprise—instead of rotating about the y-y axis as you might expect, the gyro case will turn about the z-z axis. You can see the effect in figure 6–1B. This is called PRECESSION—a very important characteristic of a gyro.

Similarly, going back to figure 6–1A again, suppose you push sideways on the top of the x-x axis (the spinning axle of the gyro), trying to rotate the wheel around the z-z axis. Then, instead of rotating about the z-z axis, the gimbal ring will turn around the y-y axis.

If you push down at point C on the gimbal ring, midway between the y-y and z-z axes, you will find that the gimbal ring rotates around the y-y axis, and that the gyro case rotates around the z-z axis. The total effect causes the gyro wheel to turn around a line lying from point C through the center of the gyro wheel.

Here's a rule that applies to all spinning gyros. The gyro will always precess at right angles to the direction of the applied force.

Now for the next question: In which direction will the gyro precess? There's a simple rule that tells you. It depends on the direction of spin of the gyro, and the direction of the applied force.

Digitized by Google

Look at figure 6–1A again. If you keep pushing down on the gimbal ring at point A, the gyro case will keep turning until the axle of the gyro wheel is horizontal. Then there will be no further precession. At that point the gyro wheel is spinning in the same direction in which the applied force is pushing.

A gyro always precesses in a direction tending to line itself up so that it spins in the same direction that the applied force is trying to turn it.

Be sure you understand that most forces, when applied to the gyro mounting, do not cause precession. For instance, you can swing the fork around in any direction, and the motion will merely be taken up in the *y-y* and *z-z* axes. Similarly, a force applied lengthwise along one of the axes will have no effect. Only those forces tending to tilt the gyro wheel itself will cause precession. Thus, you can see that if the base of the fork were attached to the deck of a ship, the gyro would have no tendency to precess as the ship rolled and pitched.

By this time you should be pretty curious about what causes this peculiar behavior of a gyro. Actually there's no magic about it at all, because it's merely a matter of the addition of vectors.

Figure 6–2 shows the gyro wheel suspended in space. The gimbal mounting has been left off to make the illustration simpler. Notice that a force is being applied to the gyro axle, tending to tilt the wheel about the *y-y* axis. Obviously, if the wheel were not spinning, point A would start to move down in direction AB.

Now what happens when the wheel is spinning? Point A still begins a motion AB. But also, it is already moving rapidly in direction AC. You already know that when a body has two motions at the same time, they add vectorially. Consequently, the final motion of point A will be in direction AD.

There's only one way in which point A can move in direction AD. The spinning axle of the wheel must MOVE to the

Digitized by Google

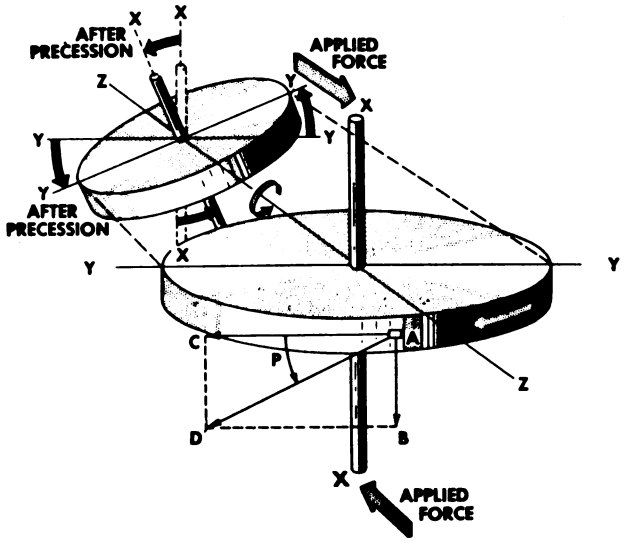


Figure 6–2.—Precession combines two movements.

position shown in dotted lines. That is, the wheel precesses about the *z-z* axis in a direction at right angles to the rotation which the applied force is trying to cause.

Let's sum it up and see what precession amounts to. You attempt to change the plane of rotation of a wheel. But the wheel already has a rotation, so it moves in a direction which combines the two rotations. It keeps precessing until it reaches a position where the applied rotation and the original rotation are in the same direction. Then the effect of the new rotation no longer tends to change the plane of the wheel, and precession stops.

Another important fact to remember is that a gyro will precess only as long as the precessional force is applied. Once the force has been removed the gyro will continue to spin in the new position, maintaining its axle fixed in space.

EFFECT OF FRICTION, APPARENT ROTATION, AND LATITUDE

Next, let's see what factors affect the STABILITY and PRECESSION of a gyro. You might think from the preceding descrip-

Digitized by Google

tion that the gyro is a perfect instrument, but such is not the case. First, it is impossible to make the gyro mountings frictionless. Friction affects the free movement of the gimbal system. Then, too, the gyro displays rigidity of the plane of rotation in space. But the earth spins through space. The result is that the gyro appears to rotate 360° a day in a direction which depends on the earth's rotation, and on the LATITUDE in which the ship is operating. However, if you know that these errors exist, you can correct them. Let's examine the effects of friction first of all, and then determine a corrective force.

Keeping the Gyro Vertical

Go back to figure 6–1 again, and suppose the base of the fork is fastened to the rolling and pitching deck of a destroyer. A roll of the ship tilts the fork, so as to lower the nearest prong. This should have no effect on the gyro. The gyro case should rotate on the *z-z* axis, and the gyro should stay vertical. But suppose there is a little FRICTION in the *z-z* bearings. This will exert a slight drag on the gyro case, tending to rotate the gyro about the *z-z* axis causing the gyro to precess away from the vertical, about the *y-y* axis.

As you already know, one of the main functions of the gyro is to maintain a TRUE VERTICAL on a rolling and pitching ship. The instrument which employs the gyro in this way is called a stable element or a stable vertical depending upon its application. They have one thing in common—both instruments accurately maintain a true vertical.

The bearings used in these instruments are nearly frictionless, but there is always enough friction to cause trouble. Over a period of time, these slight frictional forces will move the gyro a long way from the vertical. That means you need some corrective force which will bring the gyro back to the vertical when it wanders away. This force is provided by the gyro ERECTING SYSTEM.

The most common type of erecting system consists of two tanks of mercury, fastened to opposite sides of the gyro case.

Digitized by Google

The two pools of mercury are connected at the bottom by a small tube (fig. 6–3). An air tube connects the tops of the two tanks in order to prevent the formation of a vacuum.

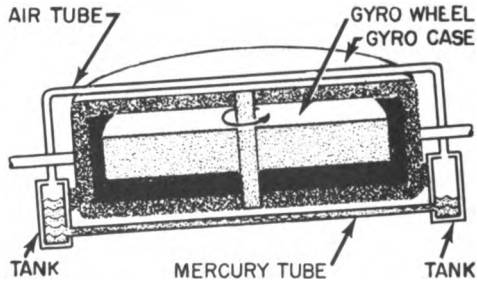


Figure 6–3.—Mercury system of a stable vertical.

Figure 6–3 is a schematic view of the gyro case with the gyro tilted away from the vertical. Naturally, the mercury runs from the high tank into the low tank. Therefore the low tank becomes HEAVIER than the high tank. This sets up a force which tries to tip the gyro farther. The gyro resists this force and precesses to one side causing the top of the gyro axle to tilt toward you.

So far, not much has been accomplished toward getting the gyro back to the vertical so let's study this next. Notice that the tube connecting the two tanks is rather small. Therefore the mercury flows slowly. After the case is tilted, it takes nearly a second for the mercury to find its level.

Also, the fork is continuously being rotated by a small motor at a constant speed of 18 times a minute. (Figure 6–4 is a schematic diagram of the gimbal-rotation system and mercury-ballistic system.) This rotary speed is such that during the second that it takes for the mercury to flow into the low tank, the fork and the entire gimbal assembly has rotated 90°. As before, the weight of the mercury is trying to tip the gyro sideways, but this time at a point 90° away from the actual tilt. Thus, the gyro precesses back toward the VERTICAL.

You will see this more clearly if you think about what

Digitized by Google

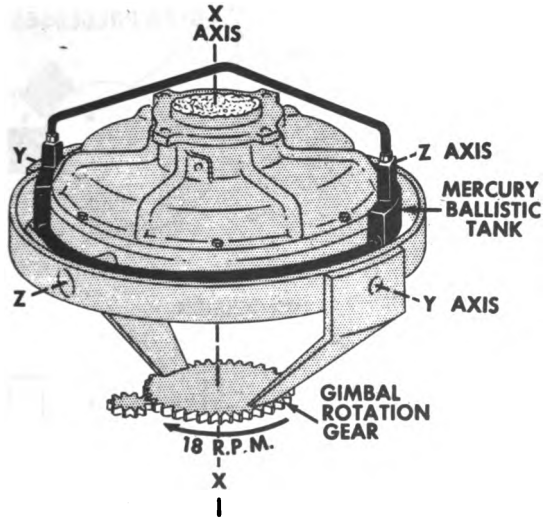


Figure 6–4.—Gimbal rotation.

happens during one rotation of the fork. The result is indicated in figure 6–5 in which you are looking straight down at the top of the gyro case and the mercury tanks. Understand that this diagram is purely schematic. It is intended to give you an idea of the principle involved, not a complete picture of what happens to a gyro in actual operation.

Suppose that the gyro axle is suddenly tilted toward the north at an instant when the mercury tanks are lined up north and south (fig. 6–5A). Mercury starts to flow into the north tank, but at first no precession occurs because of the lag or time delay in the mercury flow.

As the case rotates, the low tank is moving toward the east and is filling up with mercury. As the lower tank fills, the gyro begins to precess faster and faster in a generally southeasterly direction. By the time the low tank is full, it is headed east (fig. 6–5B) and the gyro is precessing rapidly south.

Continued rotation puts the loaded tank on the high side, and the mercury begins to flow out of it (fig. 6–5C). But

Digitized by Google

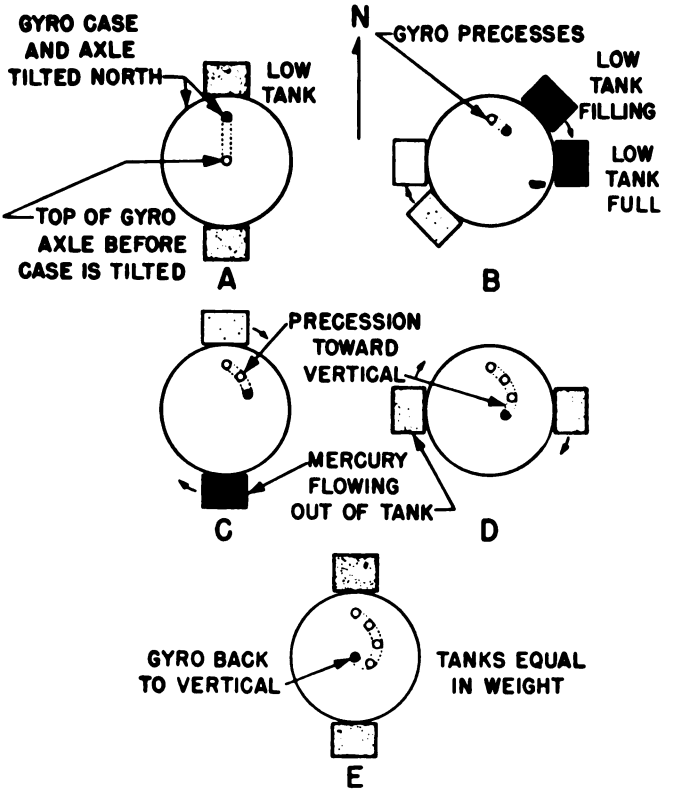


Figure 6–5.—Effect of rotating the fork.

the tank is still heavy, and therefore the gyro precesses generally southwest (fig. 6–6D). By the time the tanks are again lined up north and south, the mercury in the two tanks has equalized (fig. 6–5E). The second tank is now the low tank. It begins to fill up, and the entire process repeats.

You can see that the easterly and westerly precessions tend to cancel. The net effect is a precession toward the south, bringing the gyro back to the vertical.

Thus, you can see that whenever the gyro is started, the mercury system will bring it quickly to the vertical. And at any time the gyro wanders off the vertical, the mercury system will bring it back.

Digitized by Google

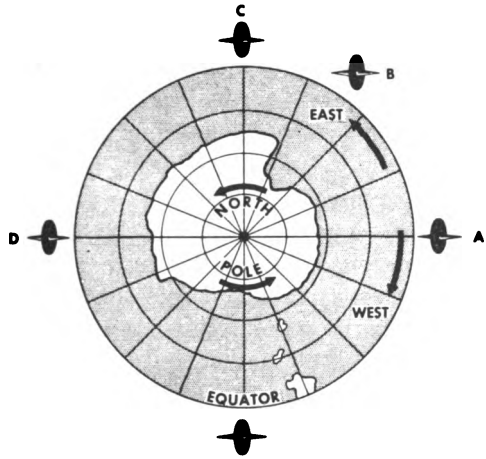


Figure 6–6.—Apparent rotation at the equator.

Ask one of the Fire Control Technicians in your division to start the stable element or stable vertical on your ship so you may watch the GIMBAL-ERECTING SYSTEM in action. You'll notice that at first the gyro will precess rapidly toward the vertical. But you'll also notice that the erecting system may require as much as 10 minutes of time to correct the last few minutes of error. This is because as the gyro comes nearer to the true verticle, less mercury flows from one tank to the other during a rotation of the gimbals. Consequently the precessional force is small and the rate of precession is very slow. In some gyro systems—the master gyro compass, for example—it may take several hours for the gyro to finally settle down in its true position.

Let's review the main purposes of the gimbal-erecting system of a stable element or stable vertical. First of all, it brings the gyro to the true vertical when the gyro is started. Second, it compensates for the effect of friction and other irregularities in the gimbals which could cause the gyro to precess away from the vertical.

Digitized by Google

A few pages back we mentioned that there are two kinds of action which tend to pull a gyro out of the vertical. One of these is the random effect of bearing friction and other similar irregularities. You have seen how a mercury-erecting system overcomes this effect.

In addition to these random actions, the ROTATION OF THE EARTH has a continuous effect on the gyro. Remember that gyroscopic stability means that a gyro axle tries to maintain a fixed direction in space. But the earth, as it rotates toward the east, is rolling under the gyro. Therefore, to an observer standing on the earth, the gyro appears to keep tipping westward.

This effect known as APPARENT ROTATION is shown in figure 6–6. The figure is a view of the earth as it would appear if you were looking down on the north pole. Imagine that a gyroscope has been erected on the equator at point A with its axis vertical (perpendicular to the surface of the earth), and that because the gyroscope has frictionless bearings and no erecting system you must rely on gyroscopic stability to keep it vertical. After a few hours, the rotation of the earth will move point A to the position marked B.

The gyro still heads in the same direction in space, but it is no longer vertical. Its axis is no longer perpendicular to the earth's surface at that point. To anyone standing on the earth, it appears to be leaning to the west. After 6 hours, when the earth has made a quarter turn, the gyro will be horizontal, as at C. After 12 hours (at position D) it will have turned completely over and will be upside down. And after 24 hours, the gyro will have made a complete revolution.

In other words, the gyro is tilting WESTWARD at a rate of 15° per hour.

The mercury-erecting system of the stable vertical won't quite prevent all of this tilt. The gyro, therefore, must be made to precess EASTWARD at 15° per hour.

Digitized by Google

Now when the gyro is truly vertical, the mercury system causes no precession. The mercury affects the gyro only when the gyro is tilted. And so, if we were to rely on the mercury system to produce the required eastward precession, the gyro would always lean slightly to the west. It would never be truly vertical, like it should be for efficient fire control. An error would always persist, being maximum at the equator, and gradually decreasing to zero at either pole.

When a gyro is vertical, therefore, you correct for the effect of the earth's rotation at all times by applying to the gyro some force that will cause a steady eastward precession. This means that in dealing with Navy stable elements or stable verticals the top of the gyro axle must be pushed northward.

This can be done by extending a small arm northward from the top of the axle, and by hanging a weight on the north end of the arm as in figure 6–7. The weight will keep trying to tip the axle northward, and this will cause an eastward precession.

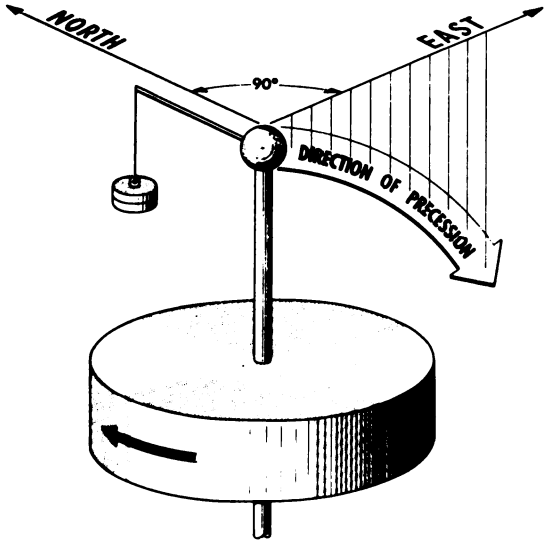


Figure 6–7.—Correction weight.

Digitized by Google

Up to now it's been assumed that the gyro is located at the equator. A little thought will show you that if the gyro were placed at the north or south pole, the rotation of the earth would have no tendency to move it out of the vertical. So you would expect that, at points on the earth between the equator and the pole, the gyro would tilt westward at a speed less than 15° per hour. This is true, and figure 6–8 shows you why. If a gyro is set vertical at A, it will move to point B in 12 hours, and will tilt through an angle of 180° − 2 × latitude of A—instead of through 180° as it would at the equator.

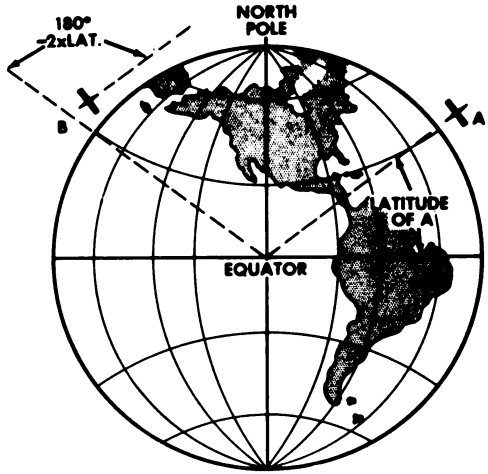


Figure 6–8.—Effect of earth's rotation at mid-latitudes.

This means that the precessional force should be adjusted as you sail toward higher or lower latitudes. You can slow down the precession by moving the compensating weight inward on the arm, closer to the gyro axle. The arm has markings on it to show you the correct position of the weight for any latitude (fig. 6–9). For this reason, the weight is called the LATITUDE-CORRECTION WEIGHT.

One final point—how are you going to be sure that the latitude-correction arm is always headed north while the ship and the stable vertical are turning?

Digitized by Google

This is accomplished by mounting the arm on the rotor of a small synchro motor attached to the gyro case. The synchro receives own ship's course, called *Co*, from the ship's gyro compass. Thus the rotor will always maintain an angle, with the electrical zero of the synchro stator, equal to the angle between the north mark on the compass card and the lubber's line (ship's head). If the electrical zero of the stator were on the fore-and-aft line of the ship, the arm would always point north.

However, the gyro assembly, as you learned earlier, is rotating at about 18 r. p. m. In order to keep the arm on north, the synchro rotor must turn backward, relative to its stator, at 18 r. p. m. So the signal from the gyro compass is passed through a SYNCHRO-DIFFERENTIAL GENERATOR which has its rotor geared to the rotating fork of the gyro, thereby eliminating gimbal rotation. Also as you will learn later,

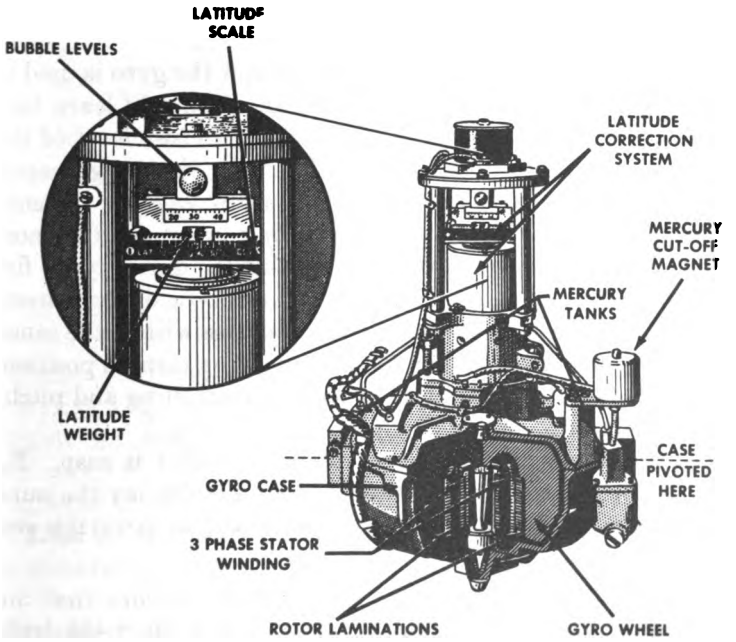


Figure 6–9.—Gyro case of the stable vertical.

Digitized by Google

the entire stable element or stable vertical is turned as the director trains in order to keep its measuring elements lined up with the line of sight. So the signal is passed through a second differential generator which takes out director train.

Thus, the synchro rotor receives (in reverse) all the movements of the gyro compass, and the director movements, with the result that the zero mark on the latitude-correction arm always heads north.

Figure 6–9 shows the actual appearance of the gyroscope and its case. Notice, in the cutaway portion, that the GYRO WHEEL is the rotor of a 3-phase a-c induction motor. The case forms the motor stator. This gyro-driving motor is operated by 70-volt 146-cycle a. c. obtained from a special MOTOR GENERATOR set. The 146-cycle current is used in order to permit high gyro speeds. The maximum speed which can be obtained from a 60-cycle current with an induction motor is only 3,600 r.p.m., but 146-cycles permits nearly 146 times 60, or 8,760 r.p.m.

Later on you will learn more about how the gyro is used in the stable element and stable vertical. You will learn how the stable vertical measures the level and cross level of the correction angles and transmits them to the rangekeeper.

Different systems use different types of erecting systems. However, the mercury gimbal-erecting system is the most common. You will learn other types later during your fire control experience. But no matter what type of gyro-erecting system you encounter, its basic purpose will be the same. It helps the gyro to find and maintain a true vertical position, which is used to correct gun orders for the rolling and pitching of the ship.

If you know the basic gyro theory, the rest is easy. No matter how the gyro is used, it will always display the same familiar characteristics—RIGIDITY OF PLANE OF ROTATION and PRECESSION.

RATE-OF-TURN GYROS

A good example of another use of the gyro is the lead-computing gun sight. It uses a pair of RATE-OF-TURN GYROS.

Digitized by Google

A rate-of-turn gyro is nothing more than a simple gyroscope which is installed to take advantage of PRECESSION. This precession is carefully measured in terms of bearing and elevation tracking rates which, after certain modifications, becomes gun-elevation and gun-train lead angles.

Consider the case of a high-speed jet fighter sweeping by your ship at a 1,000-yard range. His bearing rate would be so fast that it would tie an ordinary computing system in knots trying to calculate gun-train and elevation orders. These targets are dangerous and have to be knocked down. This means that some type of computing mechanism must be used; a type which is still faster than the ones using the mechanical components you have studied in previous chapters. The GYRO is the answer.

You will remember that, among other factors, the rate of precession of a gyro is proportional to the external force applied to the gyro.

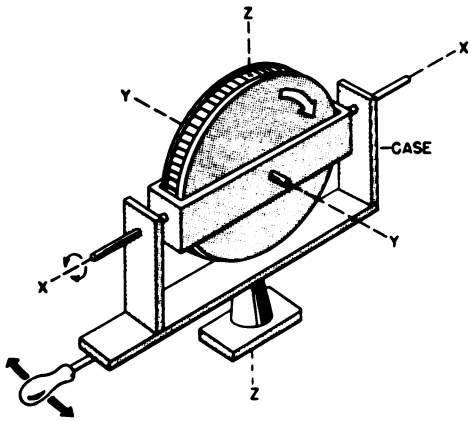


Figure 6–10.—Rate-of-turn gyro mounting.

Look at the gyro installation in figure 6–10. The gyro is spinning in a vertical plane. It has freedom of movement in two coordinates only—its spin axis and the x-x axis. Movement about the z-z axis is controlled by positioning the case with the attached handle.

Digitized by Google

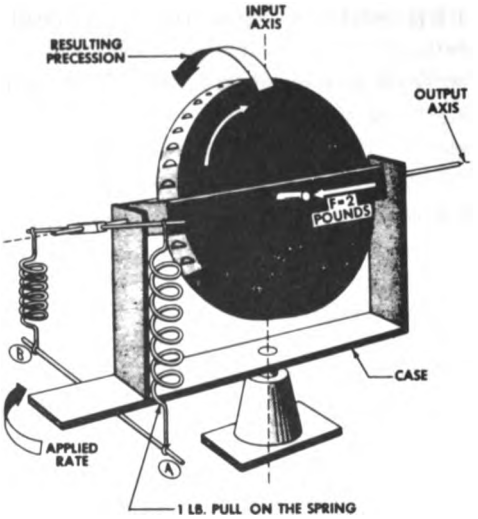


Figure 6–11.—The rate-of-turn gyro precesses.

If you attempt to change the plane of rotation of the gyro by rotating the case about the *z-z* axis, the gyro will precess about the *x-x* axis as shown in figure 6–11. Offhand, the gyro doesn't appear to be obeying the laws of precession. But stop to consider this for a minute. Attempting to turn the gyro case is the same as applying a horizontal force on the spin axle, as shown by the arrow F.

A force applied at F will cause the gyro to precess at right angles to the force. Likewise, attempting to turn the gyro case will cause the same result. The gyro will precess as shown by the arrows, around the *x-x*, or precession axis.

Since the rate of precession is proportional to the applied force, you can increase the rate of precession by increasing the speed with which you are moving the handle. In other words, you have a RATE-OF-TURN GYRO. The faster you turn the handle, the more the gyro will precess, *because the amount of precession is proportional to the rate of turn.*

This characteristic of a gyro, when properly controlled, fits the requirements of a high-speed lead-computing gun

Digitized by Google

sight. Let's see what is necessary to control the gyro properly.

In figure 6–12 is shown the method of restraining (controlling) the precession of a gyro to permit the calculation of a lead angle. A pair of SPRINGS have been attached to the crossarm on the x-x shaft. These springs serve to restrain the FREE precession of the gyro. The gyro is harnessed to produce some useful work.

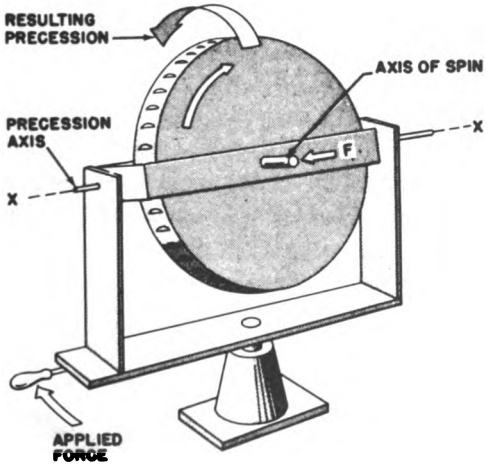


Figure 6–12.—Precession of a restrained rate-of-turn gyro.

We can say that as a gyro precesses, it exerts a certain force which is proportional to the momentum of the spinning wheel and the applied force.

For example, suppose you rotate the gyro case at a speed which is proportional to applying a horizontal force of 2 pounds at F as shown in figure 6–12. Obviously, the gyro will precess; and as it does, it will cause the crossarm to pull up on spring A with a certain force—say 1 pound. (This would vary with the length of the crossarm.)

If you CONTINUE to turn the gyro case at this rate, the precession of the gyro will continually exert a pull on the

Digitized by Google

spring. More precisely, the gyro will precess until the 1-pound pull of the crossarm is exactly counterbalanced by the tension of the spring.

The gyro will continually try to precess farther, but since its pull is balanced by the tension of the spring, it will remain in a fixed position as shown in figure 6–12. That is, it will remain in the precessed position as long as you continue to rotate the case at the same, constant speed.

When you stop moving the handle, it is equivalent to removing the force at F, and the gyro stops precessing. The spring is still exerting a pull, however, so it pulls the crossarm back to the horizontal.

Suppose you rotated the case twice as fast as before. That would be equal to a 4-pound force at F and a resulting 2-pound pull by the crossarm on spring A. So the gyro would precess twice as far before the tension on the restraining spring equalled the pull of the crossarm.

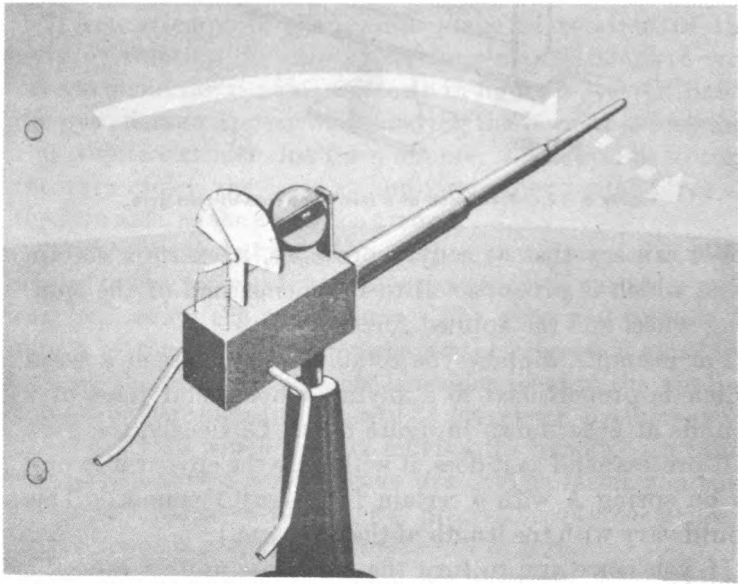


Figure 6–13.—The gyro indicates the lead angle.

Digitized by Google

Boiling it down, the faster you rotate the gyro case the farther the gyro will precess before the pulls of the crossarm and spring are equal, and the gyro comes to rest.

Outside of a few refinements, that's about all there is to a simple lead-computing gun sight. Instead of turning the gyro case with a handle, the case is mounted on a 20-mm gun as in figure 6–13. Then, as you train the gun to follow a fast moving target, the gyro precesses. Notice how the precession of the gyro moves the pointer across the scale. By calibration of the scale, the pointer could be made to indicate lead angle.

When studying lead-computing gun sights you will learn how these gyros are actually used in a sight. You will learn that the tension on the restraining springs is calibrated according to range to the target. Instead of pointers indicating lead angle on a scale, you will learn that precession of the gyros moves a complicated system of linkages and mirrors causing an illuminated reticule to be displaced by the correct lead angle.

The Navy has many different kinds of sights that depend on the gyro to compute lead angle. However the basic principle of all of them depends on the two characteristics of a gyro—RIGIDITY OF PLANE OF ROTATION and PRECESSION.

QUIZ

Select the answer (*a*, *b*, *c*, or *d*) which BEST completes the statement or answers the question.

1. The property of any revolving wheel to keep spinning in the same plane until some outside force acts upon it is called
   (*a*) gyroscopic action.
   (*b*) steering ability.
   (*c*) gyroscopic stability.
   (*d*) precession.

Digitized by Google

2. Precession is caused by
   (*a*) forces which tend to tilt the gyro wheel.
   (*b*) forces applied lengthwise along one of the axes.
   (*c*) most forces applied to the gyro mounting.
   (*d*) swinging the fork in any direction.

3. What accounts for the gyro axle's trying to maintain a fixed direction in space?
   (*a*) Continuous precession.
   (*b*) Outside forces.
   (*c*) Earth's rotation.
   (*d*) Gyroscopic stability.

4. At the equator, the earth's rotation will cause a gyro to
   (*a*) tilt to the east.
   (*b*) tilt to the west.
   (*c*) tilt to the north.
   (*d*) remain vertical.

5. At the equator, how many degrees per hour will the earth's rotation cause a gyro to tilt?
   (*a*) 0°.
   (*b*) 15°.
   (*c*) 90°.
   (*d*) 180°.

6. At which of the following places would a gyro require the MOST precessional force to counteract the earth's rotation?
   (*a*) North pole.
   (*b*) 45° north or south latitude.
   (*c*) Equator.
   (*d*) South pole.

7. At which of the following places would a gyro require the LEAST precessional force to counteract the earth's rotation?
   (*a*) North pole.
   (*b*) 45° north latitude.
   (*c*) Equator.
   (*d*) 45° south latitude.

8. The weight on the gyro axle arm of the stable element has markings to show
   (*a*) true north and true vertical positions.
   (*b*) correct positions for any latitude.
   (*c*) the amount of eastward precession.
   (*d*) changes in elevation.

Digitized by Google

9. An arm, with a weight, is extended from the stable element gyro axle to
   (*a*) cause a steady westward precession on the gyro.
   (*b*) tip the gyro slightly to the north.
   (*c*) balance the gyro in all latitudes.
   (*d*) counteract the westward tilt of the gyro.

10. The zero mark on the latitude correction arm of the gyro axle always beads
   (*a*) north.
   (*b*) east.
   (*c*) south.
   (*d*) west.

11. The stable element is righted by the combined action of the
   (*a*) mercury ballistic tanks and gimbal rotation.
   (*b*) mercury ballistic tanks and latitude-correction weight.
   (*c*) latitude-correction weight and gimbal rotation.
   (*d*) latitude-correction motor and mercury ballistic tanks.

12. Any friction which might cause the stable element to precess away from the vertical is compensated by the
   (*a*) latitude-correction weight.
   (*b*) latitude-correction motor.
   (*c*) gyro erection system.
   (*d*) friction compensation weight.

13. The rate-of-turn gyro measures bearing and elevation tracking rates by using the
   (*a*) bearing and elevation lead angles.
   (*b*) speed of rotation.
   (*c*) amount of precession.
   (*d*) rate of precession.

14. As the rate-of-turn gyro precesses, it exerts a force against the springs which is proportional to the
   (*a*) momentum and mass of the spinning wheel.
   (*b*) momentum and speed of the spinning wheel.
   (*c*) momentum of the spinning wheel and the applied force.
   (*d*) mass of the spinning wheel and the applied force.

15. The rate-of-turn gyro will remain in the precessed position as long as the case is
   (*a*) in accelerated motion.
   (*b*) rotated at the same constant speed.
   (*c*) held stationary.
   (*d*) tilted forward about the spin axis.

Digitized by Google

Digitized by Google

CHAPTER 7

LINKAGE COMPUTING MECHANISMS

Until recently, linkages were not widely used as computing mechanisms in fire control equipment. Where they were in use, there was little chance for fire control technicians to learn their inner workings. For example, in the early days of World War II an AA barrage computer was supplied to vessels which had no AA directors. This AA barrage computer (designated Mk 7) proved useful in computing sight angles, sight deflections, and fuse time for manual introduction into the sight yoke assembly of individual guns. Fleet personnel, however, were not permitted to service this barrage computer, thus restricting the opportunity for fire control technicians to become acquainted with the linkage type of computing mechanisms.

Since the war, the Navy has approved the use of these mechanisms in various computers. The most common of these is the Mk 42, which is a part of the GFCS Mk 56. A second is in the computing mechanism of the Mk 4 attack director (antisubmarine defense). Other applications will doubtless be encountered. Meanwhile, since the type of linkages used in the computer Mk 42 and the attack director Mk 4 are designed to be adjusted aboard ship, the fire control technician must have a working knowledge of the theory of operation and the mechanics of linkage mechanisms.

Linkage mechanisms which solve ballistic equations are, in some respects, superior to cams because they have much

Digitized by Google

less friction. Moreover, ball and roller bearings can easily be adapted to linkage mechanisms so that mechanical power amplifiers are not necessary. The over-all mechanism can be so designed that its mechanical advantage will overcome the bearing friction encountered. Thus, moving an input lever of a linkage mechanism may be compared to operating the long arm of a simple lever.

In addition to being free from excessive internal friction, a linkage mechanism can, by proper design of the linkage elements, be made compact, mechanically rugged, and nonresonant below 30 cycles per second. Its operations can be made independent of temperature expansion by making all parts except small fittings of the same material—preferably aluminum.

Due to differences in ballistics and improved methods of computation introduced in later models, the linkage computing mechanisms differ widely among machines. However, they all use the same basic elements and have the same general type of construction. Therefore, our examination of linkages logically begins with the linkage elements which are considered fundamental because they cannot be further broken down.

FUNDAMENTAL COMPONENTS

A photograph of one linkage computer now in use is shown in figure 7–1. The linkages there are supported by three castings. The electronic computing devices bolted on the rear side of the castings cannot be seen.

The figure shows that several familiar units including shafts, bearings, racks, and pinions are used in the linkage computer. However, since certain applications of these units are new, they will be discussed along with the special mechanisms found only in linkage computers.

Figure 7–2 shows a shaft assembly from the linkage unit, with its bearings and bearing support. In this example, the lower bearing is seated in a boss on the under side of

Digitized by Google

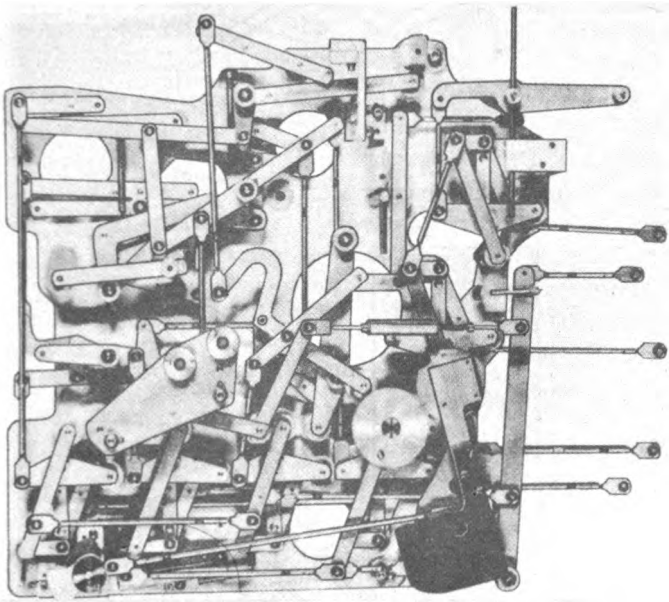


Figure 7–1.—Top view of a linkage computer.

the linkage support casting; the upper bearing is carried in a plate secured by screws and dowels to a boss on top of the casting. This construction is used for relatively long shafts which must carry a lever or link some distance above the level of the support casting. For shorter shafts, the upper bearing is seated in the casting in the same manner as the lower bearing. Both bearings are pressed into their seats and staked in place. Some bearings, like the lower one in the illustration, are seated against machined shoulders; others, like the upper one, are seated against snap rings set in grooves.

The shaft is grooved near the top and bottom to receive snap rings which hold it in place. A spring washer and a plain washer are assembled between the upper bearings and snap rings to prevent end play. The lever or gear carried by a shaft is usually pressed on and may be seated

Digitized by Google

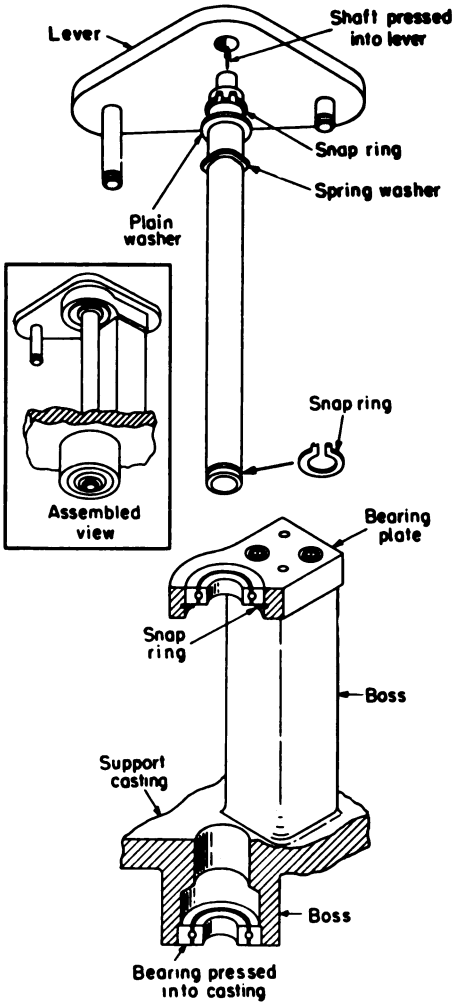


Figure 7–2.—Typical shaft assembly.

against a shoulder which is accurately spaced from the lower snap ring groove to place the gear or lever at the proper level.

Figure 7–3 shows two constructions which are used to connect levers and links. The connection at the left end of the lever is generally used for links which are supported

Digitized by Google

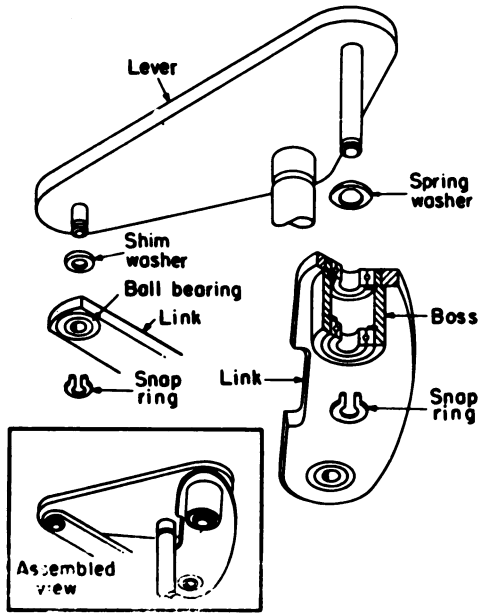


Figure 7–3.—Two types of link connections.

at both ends. A small bearing is seated in the end of the link and is staked in place. A pivot pin pressed into the left end of the lever fits the ball bearing bore. The link is assembled on the pivot pin with a shim washer to provide the proper spacing and a snap ring to hold it in place.

The connection of the link to the right end of the lever in figure 7–3 is used for links which can be supported at only one connecting point. A boss is pressed into the link at the end at which it is to be supported, and two ball bearings are seated against snap rings in the boss. The link is assembled on the pivot pin with a spring washer to prevent lost motion and a snap ring to hold it in place.

Adjustable links are used for alinement in numerous places in the linkage system. Each such link consists of two terminals and a tubular rod fastened together by right hand and left hand threads, as shown in figure 7–4. A ball bear-

Digitized by Google

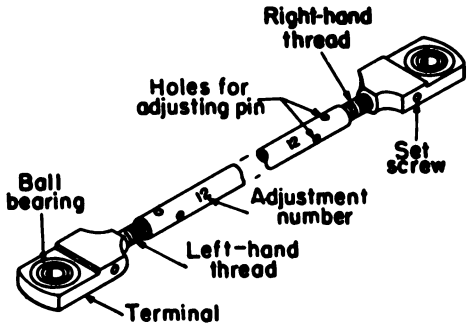


Figure 7–4.—Adjustable links.

ing is seated in each terminal to make low friction connections to other links, levers, or slide bars. With both terminals held from turning, the length of the link can be adjusted on the turn buckle principle by inserting an adjusting pin in one of the holes provided for the purpose to turn the rod. The set screws in the terminals lock the adjustment and must be loosened before a change in length is attempted. Adjustment points in the linkage assembly are numbered to aid in following alinement instructions, and the corresponding number is engraved on each of the adjustable links.

At a number of points in the linkage mechanism it is necessary to make angular adjustments of a crank arm, lever, or gear on its shaft. The construction shown in figure 7–5 is known as a compound crank, and is provided for this purpose. The lower arm is pressed on the shaft, whereas the upper arm fits freely on the shaft. A crank pin on the outer end of the lower arm projects upward into a hole in the upper arm, but since the pin is much smaller than the hole, considerable relative movement between the two arms is possible. Two set screws, threaded in opposite directions on opposite sides of the upper arm, engage the crank pin to hold the two arms in a fixed relative position. This position can be adjusted by backing off one set screw and turning in the other. The adjustment is locked by two additional set

Digitized by Google

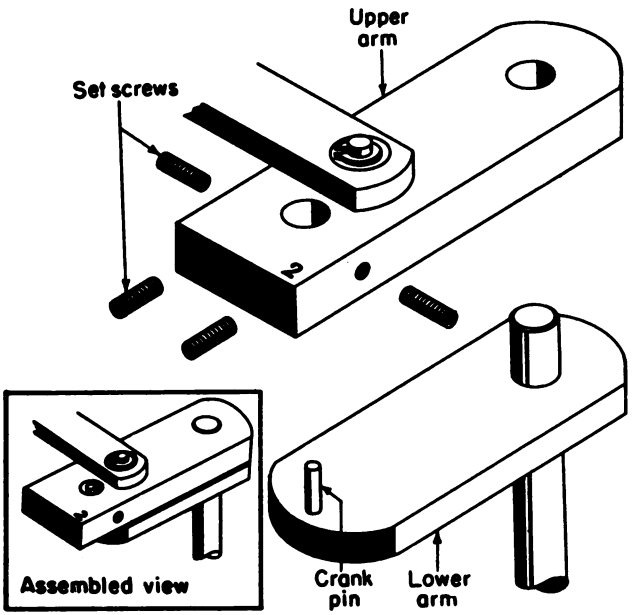


Figure 7–5.—Angular adjustment.

screws, threaded in the end of the upper arm, which bear against the first pair of screws.

Some of the quantities involved in the equations solved by linkage mechanisms are represented by a straight line motion of a slide bar such as that shown in figure 7–6. The movement of the bars or racks are guided by rollers, each of which is a small roller bearing mounted on a block; this combination is known as a roller block. Several forms of roller blocks are in use, the particular type employed in each case depending upon the function and the available space. The illustration shows four different forms. The two roller blocks on the right side of the bar are secured to the fixed structure; those on the opposite side are mounted on pivot pins. Tension springs rock the pivoted blocks to bring their rollers into contact with the bars thereby pressing the bar firmly against the fixed rollers. For greater stability, one of

Digitized by Google

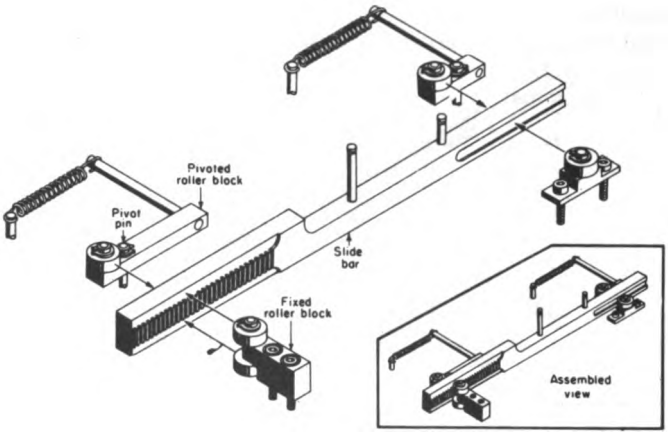


Figure 7–6.—Typical slide-bar assembly.

the fixed blocks carries two rollers, one engaging the bar near the top of the rack gear and the other near the bottom.

Motion is transmitted to or from the slide bar by means of links or by racks and pinions. Figure 7–6 shows rack teeth cut in one side of the bar and two pivot pins for linkage connections on the top.

There are several fundamental components which have been omitted here. Devices such as slides and special cranks have been left out. However, these units will be easily understood when encountered during practical experience.

ADDING AND SUBTRACTING LINKAGES

Adding and subtracting linkages are actually special types of differentials which have the same function as the conventional gear type differential—that is, to add and subtract. In this differential, however, the inputs and outputs are represented by linear movements of links rather than by the rotations of gears.

The linkage-type differential consists of a bar to which three links are connected by means of pivot pins as shown in figure 7–7A. For the present, it is assumed that the two end links are the inputs and the middle link is the output. Later

Digitized by Google

it will be shown that either end link can be made an output and that the inputs can be applied to the remaining links. If the output link is pivoted on bar D midway between the two input links, the value of the output is proportional to the sum or difference of the form $(x+y)$ or $(x-y)$.

We'll prove later that any other location of the output link on bar D will result in a sum or difference of the form $(x+Ky)$ or $(x-Ky)$. The value of the constant K is proportional to the ratio formed by the two distances determined by the offset of the output link on bar D.

Let us now see how the linkage mechanism in figure 7–7 is used to add two quantities. Addition is accomplished by moving both input links in the same direction, provided the output link is located midway between the two input links as shown here.

Assume that input X is moved so as to position the output link Z by the distance a, and the input Y is moved to position Z by the additional distance b (see fig. 7–7C). We can then say that $z=a+b$. To show how a and b are correlated with

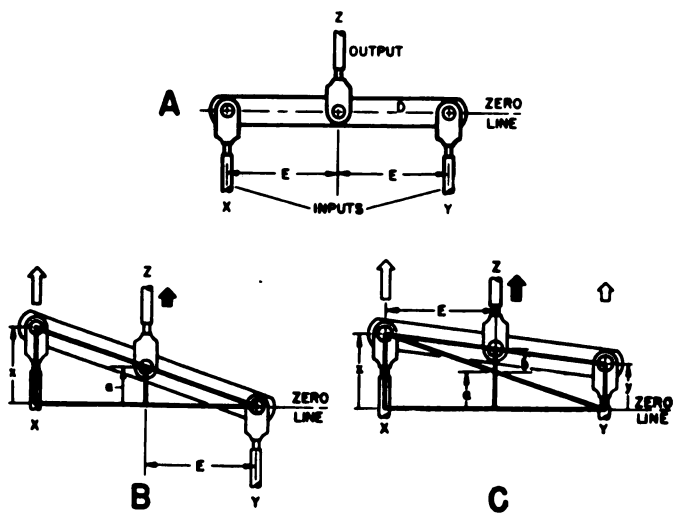


Figure 7–7.—Adding with linkages.

Digitized by Google

the inputs, let's set up two equations which state their proportionalities.

First, if input X is moved upward a distance x, the output moves a distance a, and two similar triangles are formed as shown in figure 7–7B. In these triangles

$$\frac{a}{E}=\frac{x}{2E},$$

where E is the distance from output Z to either input link as shown in figure 7–7A. Multiplying both sides by E, we have

$$\frac{Ea}{E}=\frac{Ex}{2E}$$

$$\text{or,} \qquad a=\frac{x}{2}.$$

Now, if input X remains fixed at its new position, and Y is moved upward a given amount, the output moves upward a distance b (fig. 7–7C). Making use of the upper similar triangles formed by y and b, we can equate:

$$\frac{b}{E}=\frac{y}{2E}.$$

Then, multiplying both sides by E and cancelling the E's, we have

$$b=\frac{y}{2}.$$

The total movement of the output link Z is therefore $(a+b)$, or

$$z=a+b=\frac{x}{2}+\frac{y}{2}=\frac{x+y}{2}.$$

Although the actual movement of the output link equals only one-half of the sum of the input movements, the output movement nevertheless represents their sum, but to a different scale; that is, to a different value per linear inch of link movement. If necessary, the scale of the output movement can be converted to the scale of the input movement by means of a simple linkage multiplier which will be described later.

Digitized by Google

Subtraction with the linkage differential works similarly, except, that in the example cited, b would have been a negative quantity and the Y linkage would have been moved downward. Thus z would be proportional to $(a-b)$. Of course, either a or b may assume positive or negative values.

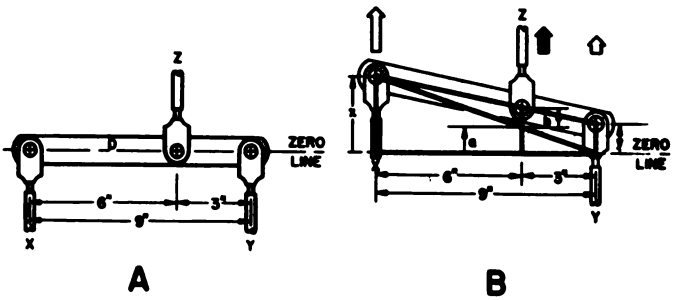


Figure 7–8.—Introducing a constant.

Next, suppose that it is desired to make $z=x+Ky$, where y is multiplied by a coefficient or constant, K. By locating the pivot point of output link Z off center on bar D, as shown in figure 7–8A, a sum of this form may be obtained. Assume bar D to be 9 inches long, and link Z to be connected 3 inches from link Y. Let link X be moved upward while Y is held; Z will move a distance a (fig. 7–8B). Employing similar triangles again, we have

$$\frac{a}{3}=\frac{x}{9}, \text{ or } a=\frac{x}{3}.$$

If X is fixed at its new position and input Y is moved upward a distance y, output Z moves a distance b (fig. 7–8B). Then, using the upper similar triangles again,

$$\frac{b}{6}=\frac{y}{9}, \text{ or } b=\frac{2}{3}y.$$

The total movement of Z is $(a+b)$, or z. Therefore, by substituting the values above for a and b, we have

$$z=a+b=\frac{x}{3}+\frac{2y}{3}=\frac{x+2y}{3}.$$

Digitized by Google

An inspection of the formula shows that the total movement of the output link is equal to one-third of the sum of x and $2y$, where the constant K of the form $x+Ky$ is equal to 2. This means the Y moves only one-half as far as X to produce a given output.

You may recall that any two of the three links of an adding and subtracting linkage mechanism can be used as the inputs, depending upon which arrangement proves the most convenient mechanically. However, thought must be given to the relative directions which the links must be moved in order to observe mathematical signs. A study of figure 7–9 will show that in that hookup, the inputs X and Y must be moved in opposite directions for addition and in the same direction for subtraction.

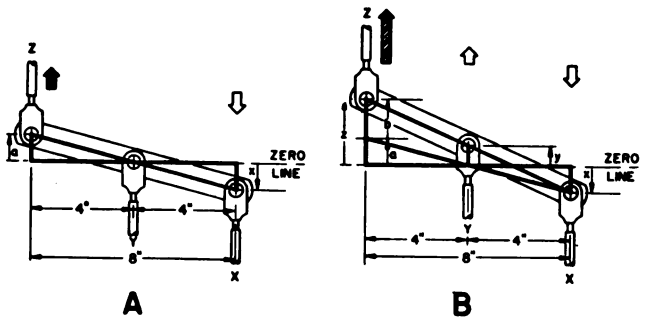


Figure 7–9.—Other arrangements.

Let us prove this. First, assume that the output link Z s located at the left end of bar D, input X is at the right-hand end, and that input Y is at the center of the bar. If input X is moved downward a distance x, while input Y remains fixed, output D will move upward a distance equal to a, as shown in 7–9A. From the similar triangles formed we can equate

$$\frac{x}{4}=\frac{a}{4}, \text{ or } a=x.$$

Second, if X is fixed at its new position and Y is moved upward a distance y, output Z moves upward a distance b as shown in figure 7–9B. Using similar triangles again,

Digitized by Google

$$\frac{y}{4}=\frac{b}{8}, \text{or } b=2y.$$

Thus, as shown in figure 7–9B, the total movement of the output link Z is $(a+b)$, or z, and

$$z=a+b=x+2y$$

where 2 is the constant K.

Subtraction with this particular linkage arrangement is accomplished by moving the two input links in the same direction. Differences of the form $(x-Ky)$ are obtained. This could be shown in the same manner.

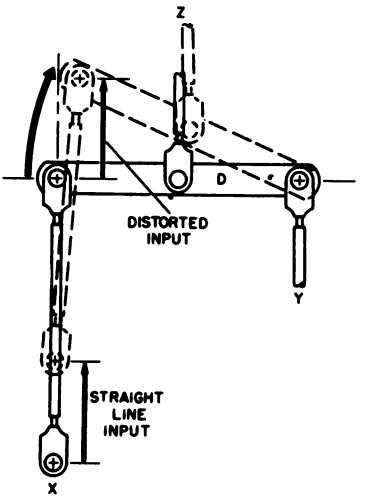


Figure 7–10.—Distortion error.

Since the length of bar D is fixed, the inputs will not actually be applied in a straight line, even though one end of each input link moves in a straight line. This distortion causes errors to be introduced in the output.

Suppose input link X is moved upward while input Y remains fixed. The upper end of link X, which is connected to bar D, moves in an arc although the lower end moves in a straight line. (See fig. 7–10.) The input to bar D is

Digitized by Google

therefore slightly less than the actual movement supplied to link X. This error, however, may be kept insignificant by limiting the angular movement of the bar D.

THE LEVER MULTIPLIER

The lever multiplier is simply a straight bar which has a fixed pivot at some point between its ends. Connected to the bar are two links; an input link and an output link. The direction of motion of the input link is parallel to the direction of motion of the output link.

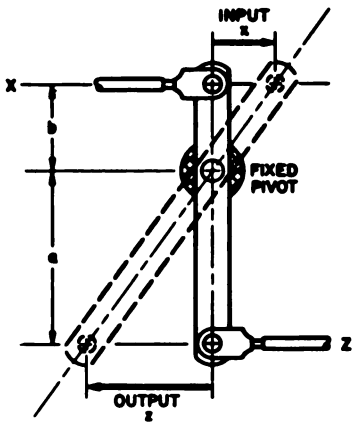


Figure 7–11.—Lever multiplier.

The output of this multiplier is equal to its input multiplied by a constant. The value of the constant depends upon the location of the fixed pivot on the bar. If the input link is moved a distance x, the output link will move a distance z as shown in figure 7–11. From the similar triangles formed, we find

$$\frac{z}{a}=\frac{x}{b}, \text{ or } z=\frac{a}{b}x.$$

Therefore, the output is equal to the input multiplied by a constant, the value of which is a/b. The fixed pivot is located along the bar at a position that establishes the required ratio of a to b as shown in figure 7–11.

Digitized by Google

Going back to figure 7–8, you will recall that in that linkage mechanism z was equal to one-third of the sum of x and $2y$, i. e., the sum of x and $2y$ divided by 3. Now, if it is necessary to clear the 3 from the denominator—that is to make the b scale the same as the x and y scales—all you have to do is multiply z by 3 with the lever multiplier shown in figure 7–11. The ratio a/b will then be equal to 3 to fulfill the above requirements.

Another lever multiplier is shown in figure 7–12. Its use is more restricted than that of the multiplier in figure 7–11 because, regardless of how the a/b ratio is varied by the placement of the input link, the output z is always larger

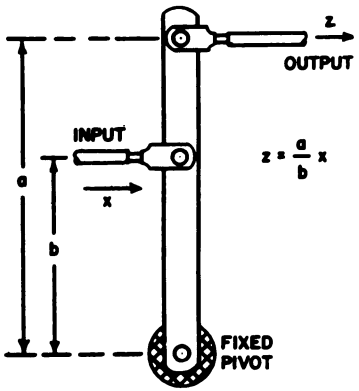


Figure 7–12.—Another lever multiplier.

than the input x. You will see how this multiplier is used when you study the three-link multiplier.

Lever multipliers are subject to distortions of the same sort as the linkage adding and subtracting mechanism. However, errors in the output can be kept small by limiting the motion of the inputs.

Bell Crank Multiplier

A variation of the lever multiplier is the bell crank multiplier shown in figure 7–13. The bell crank multiplier is a bar whose two arms form an angle and whose fixed pivot is

Digitized by Google

at the vertex of the angle. The input link is connected to one arm of the bar and an output link is connected to the other.

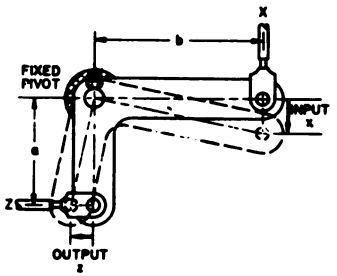


Figure 7–13.—Bell crank multiplier.

Like the case of the lever multiplier, the output is equal to the input multiplied by the ratio a/b, where a is the length of the output arm and b is the length of the input arm.

Unlike the lever multiplier, however, the direction of motion of the output is not parallel to the direction of motion of the input. The input and output motions are directed at right angles to the arms to which the links are connected. The angle between the two motions therefore depends upon the angle between the two arms. This makes the bell crank multiplier highly useful in transmitting motion around corners.

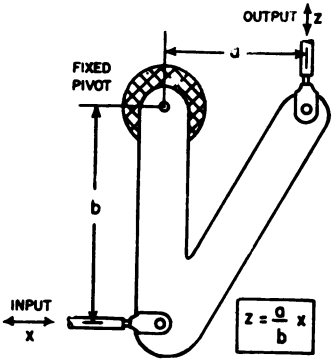


Figure 7–14.—Another bell crank multiplier.

Digitized by Google

Figure 7–14 shows another version of the bell crank multiplier. It is essentially triangular in shape, and its fixed pivot is at the upper left end of the crank. A careful comparison of figure 7–14 with figure 7–13 will show that both forms of these multipliers accomplish the same thing. You will find some bell crank multipliers which are triangular in shape. As might be expected, all bell crank multipliers function on the same principles.

Three-link Multipliers

The three-link multiplier shown in figure 7–15 is a mechanism designed to multiply two variable quantities. It is also sometimes called the XY linkage or three-bar multiplier. Although it has very little resemblance to them, this multiplier works on the same basic principles as the lever and bell crank multipliers.

The secret of the three-link multiplier lies in the ratio a/b. If the a/b ratio of the bell crank multiplier in figure

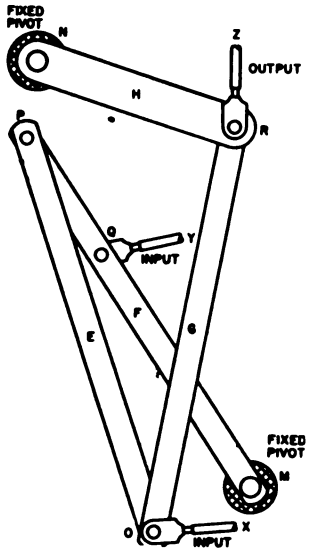


Figure 7–15.—Three-link multiplier.

Digitized by Google

7–14 could be varied by a second input, the output would be proportional to the product of the two inputs. A study of figure 7–14 indicates that the a/b ratio can be varied by hinging the bell crank in the elbow, which would facilitate the variation of output arm a, and in turn the a/b ratio.

Getting back to figure 7–15, we find that links E, F, and G are equal in length. A fourth link, H, merely guides link G and output link Z.

When pivots P and R coincide, the Y input is zero. Also, when pivot O and fixed pivot M coincide, the X input is zero. The zero position of the multiplier is established when both the X and Y inputs are at zero. When either X or Y is at zero, the output Z must also be zero because when either factor of a product is zero the answer is zero. A study of figure 7–15 will show this is true—just hold either Z or Y at zero and imagine moving the free input. Z will remain stationary.

Now let's see how the three-link multiplier works. First, visualize superimposing the bell crank of figure 7–14 over the E and G links of figure 7–15 so that pivot P corresponds to the fixed pivot. Then link E matches the fixed arm b, and distance P-R to the output arm a. We now see that the variable multiplier formed by links E and G of figure 7–15 takes the place of the bell crank multiplier of figure 7–14.

The other multiplier of figure 7–15 is the lever multiplier formed by the F link and the Y input. It works on the same principle as the lever multiplier in figure 7–12. The purpose of the link F multiplier is to determine the length of the a arm of the E-G bell crank, i. e., the distance P-R. In this way the Y input positions link E to vary the a/b ratio. Then the X input positions the bell crank multiplier, E-G, which pivots about P to position the output Z.

Here is what the three-link multiplier does mathematically: Let link E equal b and distance P-R equal a as shown in figure 7–16. Then, using the lever multiplier principle discussed with figure 7–12, we can write—

Digitized by Google

$$a=\frac{yd}{c}. \tag{1}$$

Also, using the bell crank principle, we find—

$$z=\frac{xa}{b}. \tag{2}$$

Next we substitute yd/c of (1) for a in (2) to obtain

$$z=\frac{xyd}{bc}. \tag{3}$$

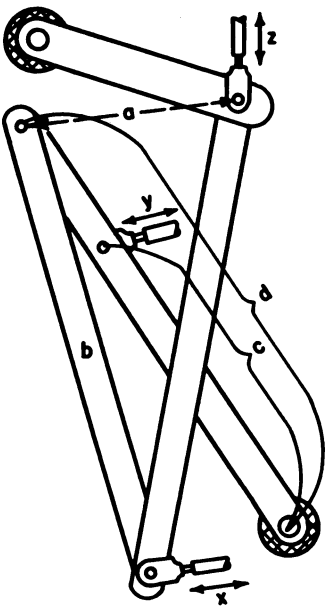


Figure 7–16.—The a/b and d/c ratios of the three-link multiplier.

But $b=d$ because, as previously stated, all three links (E, F, and G of fig. 7–15) are equal. Therefore, d and b cancel out in the equation (3) to give the final equation—

$$z=\frac{xy}{c}.$$

Since c is a fixed distance for any multiplier, it is a constant

Digitized by Google

that can be removed by means of a bell crank in the output, or simply by assigning a different value per unit of travel for the output link at the time of designing the instrument.

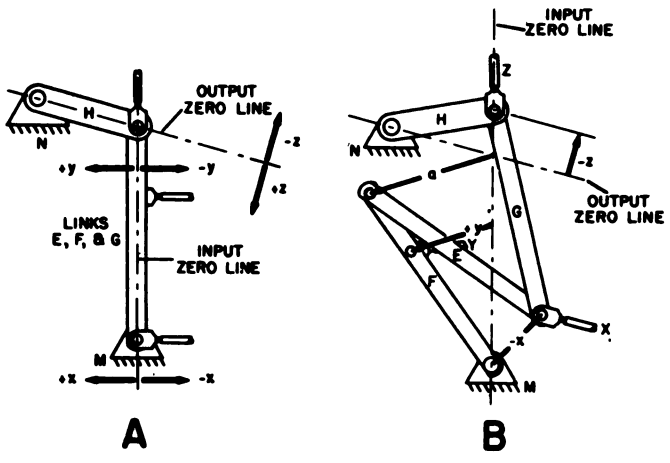


Figure 7–17.—Negative values.

Figure 7–17A shows the zero position of the three-link multiplier which was just described. If movements of the two inputs to the left of the input zero line are considered to be positive values, negative inputs of x and y can be introduced by moving the respective links to the right of the input zero line. Such a system of positive and negative directions for the inputs will result in Z movements below the output zero line to be positive, and Z movements above the output zero line to be negative. For example, assume that a negative x is multiplied by a positive y: input link Y is moved a distance to the left equal to plus y, and input link X is moved a distance to the right equal to minus x. This causes link Z to move above the output zero line a distance equal to minus z as shown in figure 7–17B. Stated mathematically:

$$z = \frac{(-x)\ (+y)}{c}.$$

Similarly, a negative y can be multiplied by a positive x, or

Digitized by Google

both x and y may be negative. Just follow the signs in figure 7–17A, and you'll have no trouble.

Like the linkage mechanisms mentioned before, distortion errors in the three-link multiplier can be kept small by limiting the range of movement of the inputs.

The three-link multiplier may be used as a divider simply by rearranging the connections. The formulas

$$x=\frac{zc}{y} \text{ and } y=\frac{zc}{x}$$

are equations derived from the multiplier equation you studied with figure 7–16. For example, to solve for x, the dividend z is put in at the Z linkage and the divisor y at the Y linkage; the quotient x becomes the X linkage position. The constant c can again be handled by the proper selection of scales.

The three-link multiplier when used as a divider has the distinct advantage of usually not requiring a follow-up to reinforce the divisor or input; this holds true only when the divisor does not approach zero.

THE ABSOLUTER

The absoluter is a linkage device used to convert linear motions of either a positive or negative value into linear motions that are always positive.

You probably haven't encountered this device before

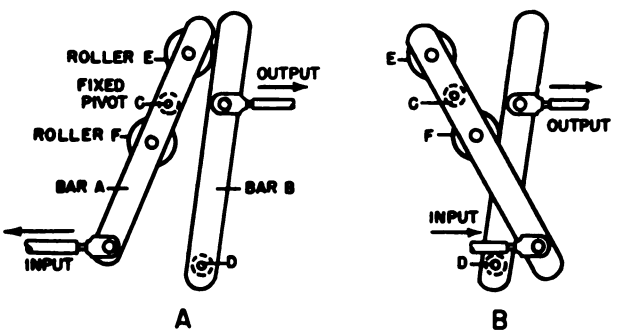


Figure 7–18.—The absoluter linkage mechanism.

Digitized by Google

unless you have been associated with the Mk 4 attack director. It is used in the Mk 4 attack director in the computation of firing time. Time can never go negative—it's either in the present or the future. Thus firing time will always be positive. However, some of the quantities used in the computation of firing time can be negative, so we must find a way to make the output of firing time positive regardless of the sign of the input quantity. This is accomplished with the absoluter. A detailed description of this mechanism follows.

Figure 7–18 shows a drawing of the absoluter linkage. You can see that movement of the input link to the left causes roller E to push against bar B, thereby moving the output link to the right a distance which is proportional to the input. Likewise, motion of the input link to the right causes roller F to push against bar B, and moves the output link to the right a distance which is proportional to the input.

It can be seen that the absoluter is composed of two lever type multipliers connected in series. Bar B works on exactly the same principle as the lever multiplier you studied in figures 7–11 and 7–12. But the action of bar A is a little different. You have one multiplier when roller E is active (fig. 7–18A), and another when roller F is active (fig. 7–18B). Thus, bar A serves as a duplex-lever multiplier. This will become more evident when you study the details of the absoluter in figure 7–19.

From your knowledge of linkage multipliers you know that a single bar multiplies by means of ratio arms. The dimensions of the absoluter shown in figure 7–19 are typical, and from them we can set up our mathematical relations. Although the actual dimensions may vary from those given here, the ratios will remain the same.

Let's apply a positive input and see how these ratios work out. When the input is moved rightward, roller F is active. The input quantity, x, is then multiplied by $\frac{1}{4}$. This ratio is formed by the relative distances that roller F and the input

Digitized by Google

link are located from the fixed pivot C in figure 7–19. Notice that roller F becomes the input to bar B. The rightward motion of roller F is therefore multiplied by the ratio 4/3.

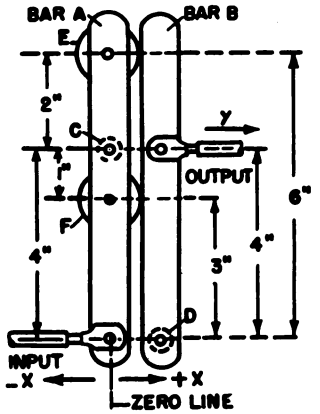


Figure 7–19.—The multiplying ratios of the absoluter.

Figure 7–19 shows that the point of contact of roller F is three inches from the fixed pivot D of bar B. We therefore find that

$$y = x\left(\frac{1}{4}\cdot\frac{4}{3}\right) = \frac{x}{3}.$$

Now apply a negative x by moving the input link to the left of the zero line shown in figure 7–19. The rightward movement of roller E (which is then active) is proportional to the ratio formed by the distances roller E and the input link are located from the fixed pivot C. The output of roller E is therefore equal to the input quantity $-x$ multiplied by 2/4, the ratio formed by the arms each side of pivot C

The motion imparted to roller E now becomes the input to bar B and is multiplied by the ratio 4/6, which is taken from the dimensions shown. Summing up,

$$y = x\left(\frac{2}{4}\cdot\frac{4}{6}\right) = \frac{x}{3}.$$

NOTE: Although x is negative in direction, the minus sign has been omitted here for simplicity.

Digitized by Google

The output of the absoluter is thus equal to one-third of the input when x is either positive or negative. As you have already learned, the constant 3 can be cleared from the denominator by multipling the output with a lever multiplier.

Distortion can here again be held to within tolerable limits by limiting the input movement.

NONLINEAR LINKAGES

Ballistic quantities such as drift and superelevation are usually computed as empirical functions of range and elevation. As you may know, empirical data is taken from experimental firing, rather than from mathematical analysis, and recorded on range tables. You learned earlier that such quantities can be reproduced mechanically by means of cams. You will now see how a linkage mechanism can do the same job, but in a new way.

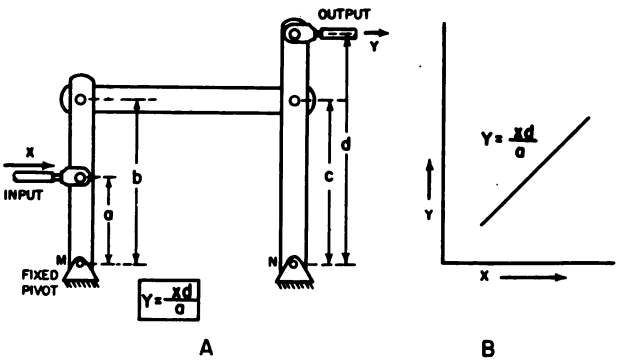


Figure 7–20.—Linear four-bar linkage.

Before discussing the nonlinear linkage, let's briefly study the linear four-bar linkage shown in figure 7–20. The fourth bar is composed of the distance between the fixed pivots M and N. The input and output levers are connected by a free link whose pivots are the same distance apart as the fixed pivots M and N. From your knowledge of single bar levers you can set up the following statement:

Digitized by Google

$$y = \frac{xbd}{ac} = \frac{xd}{a},$$

where lengths b and c cancel because they are equal. The graph in figure 7–20B shows that y varies directly with x, i. e., in a linear fashion. If the ratio d/a is changed, the slope or slant of the line will vary, but, even so, the resulting line will always be straight.

Although straight line functions are useful in fire control computers to make approximations, the curved function is the one most often encountered. As already mentioned, ballistics such as drift, time of flight, and super-elevation vary as functions of range and elevation. In such cases, the resulting line is almost always curved.

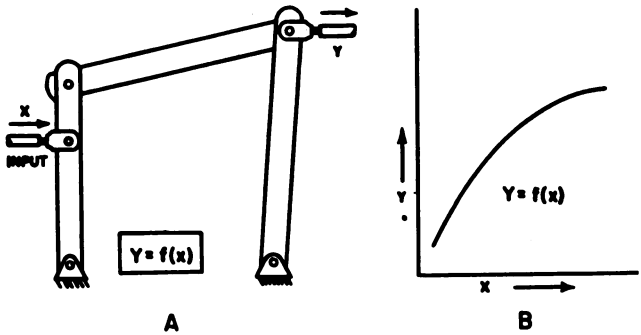


Figure 7–21.—Nonlinear four-bar linkage.

The graph shown in figure 7–21B displays the curve of y as a function of x. y is the dependent variable whereas x is the independent variable. Therefore, y corresponds to the ballistic, and x corresponds to range or elevation. Of course, what the function is depends upon the equation of the ballistic to be solved.

The nonlinear linkage of figure 7–21A computes the curved function of 7–21B. In contrast to the linear linkage shown in figure 7–20A, you'll find that no two bars of the nonlinear linkage are equal in length. Thus, the relative lengths of the input and output levers, the free link, the fourth bar, and the spacing of the input and output links from the pivot

Digitized by Google

points are chosen to fit the particular equation. As a result, the nonlinear four-bar linkage will appear in numerous arrangements, but, even so, it will easily be recognized.

DISTORTION

Although errors due to the angular movement of links and levers were cited during the discussion of each device, little has been said about how these errors are compensated. One way of preventing errors which has been mentioned is to restrict the movement of the linkages, thereby minimizing their angular motion. This is done in actual practice. But where the movement of linkages becomes large, the resulting errors are compensated for by the application of such familiar devices as bell cranks, multiplying levers, and four-bar linkages. These mechanisms should not be confused with the units used to convert from one scale to another.

One common offender in generating errors is the three-link multiplier or divider. It generates errors because its inputs must travel over comparatively long distances to accommodate the wide range of values which it multiplies and divides.

Figure 7–22 shows an actual mechanism where a three-link multiplier is compensated with a bell crank arrangement. The shaded components are bell cranks. The largest crank modifies the Y input, whereas the other crank modifies the Z output. The proper choice of the bell crank ratio arms and pivot points reduces the errors to within tolerable limits.

ADJUSTMENTS

Figure 7–22 also shows a few interesting adjustments. The A_1 and A_4 adjustments are adjustable links which you studied early in this chapter. But A_2 and A_3 are adjustments which are made differently. The A_2 and A_3 holes are lined up and an adjustment rod is inserted to keep them in position. Then the input and output quantities are checked at dials or other indicators to determine whether adjustments are necessary.

Digitized by Google

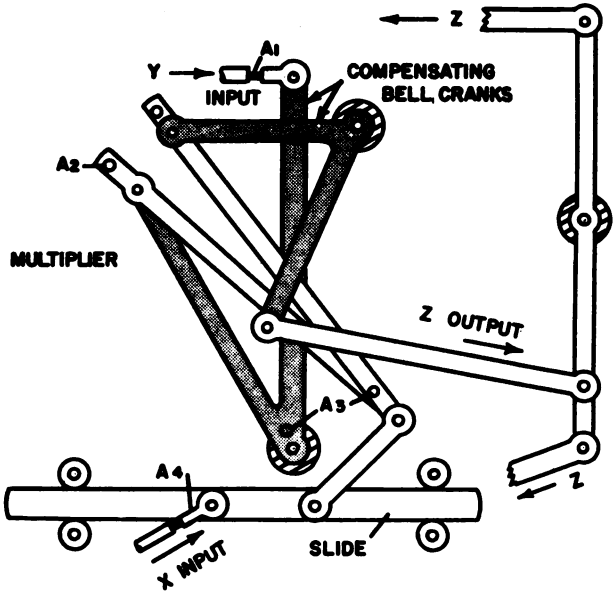


Figure 7–22.—An actual linkage arrangement.

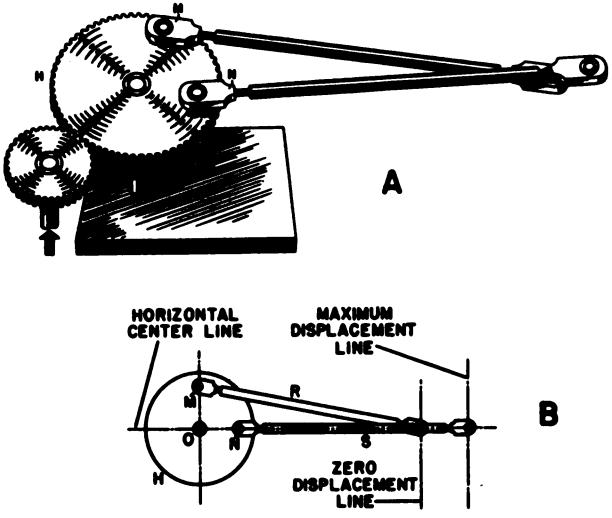


Figure 7–23.—Basic angle resolver.

Digitized by Google

ANGLE RESOLVERS

An angle resolver is a mechanism which computes the sine and cosine of an angle. In figure 7–23 is shown a simple resolver which consists of a gear H on which two crank pins, M and N, are mounted 90° apart and equidistant from the center of the gear. Attached to each pin is an output link which transmits the horizontal component of the motion of the pin as the gear rotates. The horizontal component of the displacement of pin M is proportional to the sine of the angle through which gear H rotates, and the horizontal component of the displacement of pin N is proportional to the cosine of the same angle.

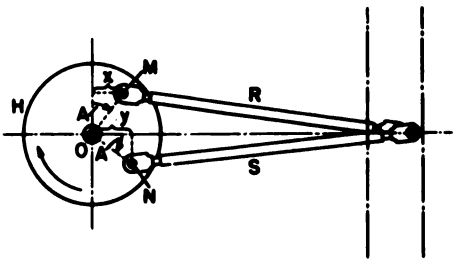


Figure 7–24.—Basic angle resolver action.

Figure 7–24 shows how the basic angle resolver works. Assume that radius OM is perpendicular to the horizontal line and the radius ON is on the horizontal line as shown in figure 7–23B. This is the zero position of the resolver; it is the position assumed by the mechanism when the angle to be resolved is zero. At the zero position, the sine of the angle is equal to zero and the output link R is at its zero displacement position. Similarly, the cosine of the angle is equal to one, or unity, and output link S is at its maximum displacement.

If gear H is rotated in a clockwise direction through the angle *A* shown in figure 7–24, link R moves to the right and link S moves to the left.

The horizontal components of the displacement of pin M

Digitized by Google

is distance x. From the right triangle formed with x as one side, we find that

$$\sin A = \frac{x}{OM}$$

$$\text{or, } x = OM \sin A$$

where OM is a constant, and the distance x is proportional to sin A. Thus, the displacement of the output link R is proportional to sin A.

The horizontal component of radius ON is distance y. From the right triangle, we find

$$\cos A = \frac{y}{ON}$$

$$\text{or, } y = ON \cos A.$$

Therefore, the displacement of output S from the zero line is proportional to cos A.

The outputs of the resolver mechanism of figure 7–23 are only approximate values. This is caused by the departure of the output links from parrallelism with the horizontal center line. The shorter the output links, the more serious this error becomes. This error is proportional to the angle the R and S links make with the horizontal. In fact, the error is equal to the length of a given output link multiplied by one minus the cosine of the angle the link makes with the horizontal center line. This error can be eliminated by adjusting the length of the output links as angle A is varied. The compensated angle resolver, now to be discussed, does this by a planetary gearing arrangement.

Compensated Angle Resolver

A sketch of a compensated angle resolver is shown in figure 7–25. The crank pins M and N are not mounted on gear H as shown in the basic angle resolver. Instead they are mounted on gears E and F, respectively. Gears E and F are bearing mounted on gear H, 90° apart and equidistant from the center of the gear. Gear G, which is concentric

Digitized by Google

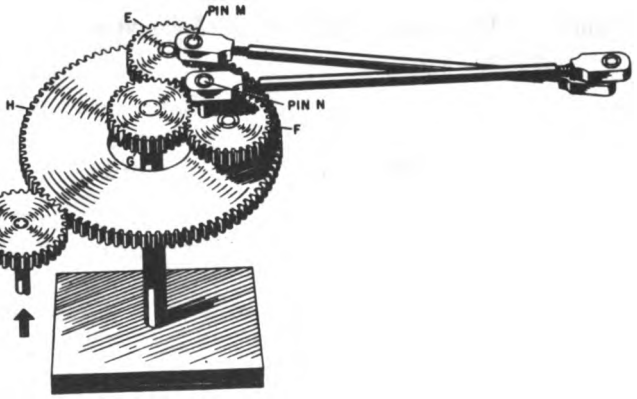


Figure 7–25.—The compensated angle resolver.

with gear H, is meshed with gears E and F. Gear G has the same number of teeth as gears E and F, and is fixed to the frame of the instrument.

As gear H rotates, it carries gears E and F with it, causing them to walk around gear G. Therefore, M and N change their positions relative to gear H; that is, they move in a circle about the centers of gears E and F. This added motion of the pins applies a correction to the output links which compensates for the error caused by the angle between the horizontal center line and the output links. In effect, the lengths of the output links are varied to balance out this error.

Although this arrangement of the compensated angle resolver does not completely correct the error caused by the angular movement of the output links, it is the most commonly used angle resolver. Its outputs are accurate enough for application in highly accurate fire control computers.

Since the construction of actual angle resolvers sometimes varies considerably from the one described in figure 7–25, the details of the typical mechanism will now be discussed. The crank disk of figure 7–26 is pressed on a shaft which is carried by the ball bearings mounted in the support casting. The crank disk shaft also mounts two gears at its

Digitized by Google

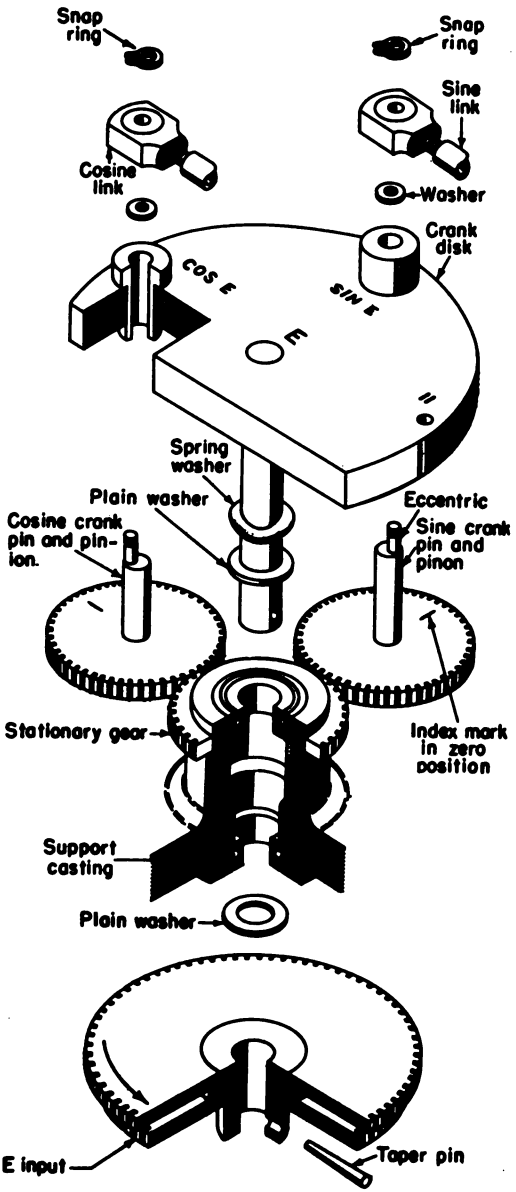


Figure 7–26.—Compensated angle resolver construction.

Digitized by Google

lower end. These two gears are rigidly mounted on a common spider. The lowermost of these two gears is driven by the *E* (elevation) input to the resolver, while the upper gear transmits *E* to other computer mechanisms. The sine and cosine crank pins are seated in bushings in the crank disk and each carries a pinion gear which meshes with a stationary gear mounted on the support casting. The sine and cosine links (or output arms) are pivoted on eccentrics at the upper ends of the crank pins. These links drive the sine *E* and cosine *E* slide bars similar to the one shown in figure 7-6.

As the crank disk is turned, the pinions walk around the stationary gear, turn the crank pins and throw the eccentrics through 180° for a 90° movement of the disk. At zero value of *E*, the sine eccentric should be on the side of the crank pin nearest the slides, and the cosine eccentric should be on the opposite side. At 90°, these positions are reversed. Index marks are provided on the two pinions to aid in assembling them with the eccentrics in the proper positions. At 0° (*E*), the index marks should line up with the centers of the crank pins and the center of the crank-disk shaft.

Go back and review figure 7-26 carefully, and mentally try to assemble the parts shown. This mechanism is very similar to several units now in use.

QUIZ

1. Which of the following does not pertain to the advantages of linkage mechanisms?
   - (*a*) They can be designed so that the mechanical advantage will overcome bearing friction.
   - (*b*) They are superior to cams in that they have much less friction.
   - (*c*) They are rugged and more compact.
   - (*d*) They can be designed to be nonresonant below the critical frequency of 60 cycles.

Digitized by Google

2. The device best adapted for converting linear motion into circular motion is the
   (*a*) link.
   (*b*) boss.
   (*c*) slide bar.
   (*d*) roller block.
3. The $(x+Ky)$ or $(x-Ky)$ form of equation is obtained from a differential-type linkage mechanism by
   (*a*) modifying one input with a multiplying bar.
   (*b*) properly locating the output link on the adding and subtracting bar.
   (*c*) shortening one input link.
   (*d*) scaling down the output with a multiplying bar.
4. Which of the following statements pertaining to the adjustable link is incorrect?
   (*a*) It has a tubular rod having right-hand threads at each end.
   (*b*) It enables the alinement of linkage components to give accurate computations.
   (*c*) The terminals are held rigid by means of set screws.
   (*d*) It is adjusted by turning the tubular rod with a pin placed in one of the holes provided.
5. Springs are used in the typical slide-bar assembly to
   (*a*) take up lost motion.
   (*b*) prevent gear chatter.
   (*c*) rock the pivoted roller blocks.
   (*d*) decrease the guide roller pressure.
6. When the output of a linkage mechanism has a constant in the denominator, this constant can be made equal to one by running the answer through a
   (*a*) resolver.
   (*b*) absoluter.
   (*c*) differential.
   (*d*) lever multiplier.
7. Subtraction is accomplished with a linkage differential mechanism by
   (*a*) exchanging the output with either input.
   (*b*) reversing the two inputs.
   (*c*) using the middle link and either outside link as the inputs.
   (*d*) using the same arrangement as is used for addition.
8. The bar of a lever multiplier has a length *a*, is pivoted about a fixed pivot at one end, has an output link at the other end, and the input link is fastened to the bar a distance *b* above the fixed

Digitized by Google

pivot. What mathematical relation will the output y have to the input x?

(*a*) $y=\frac{xa}{b}$

(*b*) $y=\frac{xb}{a}$

(*c*) $y=\frac{a}{xb}$

(*d*) $y=\frac{b}{xa}$

9. The three-link multiplier may be likened to the combination of the
   (*a*) absoluter and bell crank.
   (*b*) bell crank and lever multiplier.
   (*c*) lever multiplier and absoluter.
   (*d*) absoluter and linkage differential.
10. The Y input of the three-link multiplier varies ratio arm
   (*a*) *a*.
   (*b*) *b*.
   (*c*) *c*.
   (*d*) *d*.
11. Division can be performed with the three-link multiplier by
   (*a*) exchanging the output with either input.
   (*b*) reversing the X and Y inputs.
   (*c*) placing a bell crank in the output.
   (*d*) altering the position of the Y input link.
12. The absoluter can be compared to the combination of
   (*a*) a bell crank and a lever multiplier.
   (*b*) two bell crank multipliers.
   (*c*) two lever multipliers.
   (*d*) a differential linkage and a bell crank.
13. When the upper roller of the input bar of an absoluter is active, the equation that expresses the relationship of the output y with respect to x is
   (*a*) $y=x$ ($\frac{1}{4}\times\frac{4}{3}$).
   (*b*) $y=x$ ($\frac{4}{1}\times\frac{3}{4}$).
   (*c*) $y=x$ ($\frac{3}{4}\times\frac{4}{6}$).
   (*d*) $y=x$ ($\frac{6}{2}\times\frac{1}{4}$).
14. The sine and cosine crank pins of an angle resolver are located
   (*a*) 30° apart.
   (*b*) 45° apart.
   (*c*) 60° apart.
   (*d*) 90° apart.

Digitized by Google

15. The error due to the angular motion of the output links of a basic angle resolver can be compensated for by
    (*a*) decreasing the length of the output links.
    (*b*) offsetting the sine and cosine crank pins by a fixed amount.
    (*c*) mounting eccentric bearings in the link terminals.
    (*d*) a planetary gearing arrangement.

Digitized by Google

Digitized by Google

CHAPTER 8

ELECTRO-MECHANICAL SERVO MECHANISMS

STRENGTHENING SHAFT MOVEMENTS

The outputs of computing mechanisms such as vector solvers are often very weak mechanical signals. Output gearing often puts a strain on the computing mechanisms causing the inputs to slip. This, of course, would cause erroneous shaft positions. You will therefore find that the outputs of some computing devices are strengthened by servo motors. Servos are small fractional horsepower electric follow-up motors. In the case of the vector solver, one motor strengthens the speed output and another strengthens the angle output. In other words, the servos amplify the shaft positions. Figure 4–21 back in chapter 4 shows a simplified drawing of how the vector solver outputs are strengthened.

In other instances, the signals are sent by synchro transmission from the director, gyrocompass or other parts of the ship. These signals are received by synchro receivers and control transformers. In the case of the synchro receiver, only small loads can be positioned since its torque diminishes to zero at correspondence. Here again the servo motor is used to amplify the synchro shaft or rotor position.

Servo Motor

The servo motors used in mechanical computers are of the induction type, designed to operate on single phase, 60 cycle, 115 volt, alternating current. These motors are

Digitized by Google

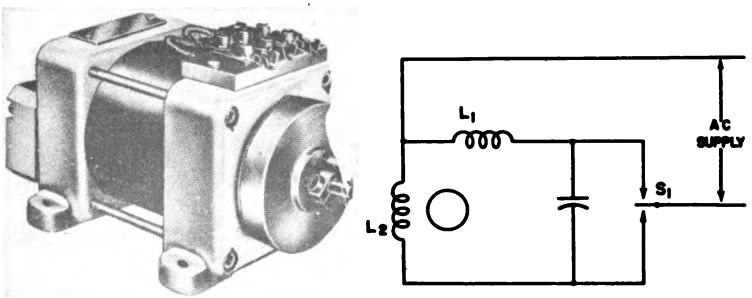


Figure 8–1.—The servo motor.

wound like two-phase motors—they have two separate identical windings. Figure 8–1 shows a photograph of the servo motor and a schematic diagram of the basic servo circuit.

Notice that the motor is easily reversed by placing switch S1 in either the upper or lower position. When the switch is in the upper position the capacitor C is in series with winding L2, causing rotation in one direction—in other words, the current in winding L2 is caused to lead the current in L1. This, as you know, causes a rotating magnetic field; you have split the phase by the insertion of the capacitor. Now, when the switch S1 is placed in the lower position, the capacitor is inserted in series with the L1 winding of the motor. Thus you have a reversible motor. We shall see shortly how, by the use of special contact arms, the servo motor can amplify shaft positions.

Go back to figure 8–1 and notice the damper on the servo shaft; this damper is required to prevent oscillations. The damper shown in figure 8–1 is a magnetic damper. Figure 8–2 shows a cut-away view of this damper.

Here is how the damper works: When the servo rotor revolves it rotates the permanent magnet, thus rotating the magnetic field set up by the magnet. The lines of force in this magnetic field cut through the steel ring as the field moves past, causing a current to be induced in the steel ring. The two copper rings merely help to distribute this current evenly throughout the steel. A second magnetic

Digitized by Google

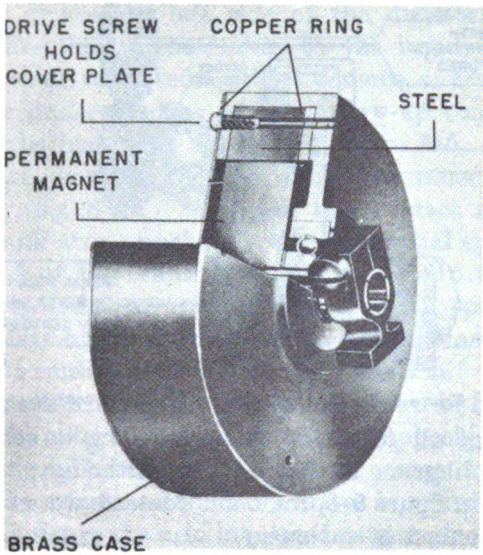


Figure 8–2.—Cut-away view of the magnetic damper.

field is set up by the induced current. Now, as the rotor turns, the permanent-magnet field and the field set up in the steel ring react together in such a way that the ring tends to be pulled in the direction of magnet rotation. Since the steel ring is attached to the case, the whole case turns. In other words, the rotating magnet exerts a torque on the case which tends to make the case revolve in the same direction as the magnet. Even small movements of the magnet will set up this magnetic couple. The magnetic damper is therefore highly effective in damping even the slightest oscillations; this is particularly helpful when the contacts momentarily touch as they drift across the point of centralization. This will be more evident when discussing the follow-up as a whole.

SERVO FOLLOW-UP

Figure 8–3 shows a simplified form of follow-up control which will be used to illustrate the general principles of

Digitized by Google

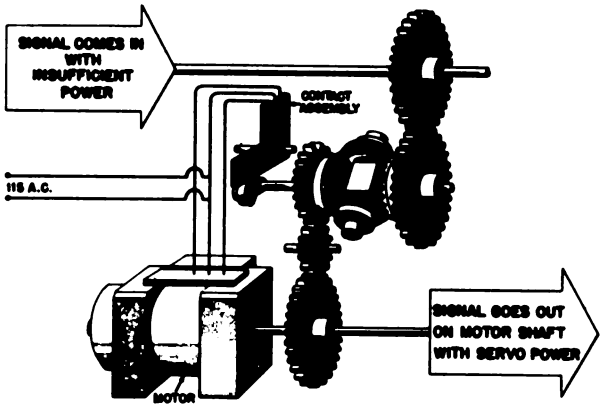


Figure 8–3.—Simplified servo follow-up control.

operation of all follow-up controls. Try to associate the schematic diagram in figure 8–1. Although it may not be evident in figure 8–3, the outer contacts are movable and the inner contact is stationary.

Briefly, here is how they work. The signal comes in with insufficient power and positions one side of the differential. This causes the outer contacts to move one way or the other making contact with the central contact. The servo, therefore, drives the load and, at the same time, the other side of the differential in response to the signal.

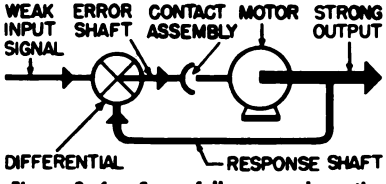


Figure 8–4.—Servo follow-up schematic.

A schematic of the mechanism in figure 8–3 is shown in figure 8–4. Going over the operation of the servo follow-up again, we find that the differential simply measures the difference or error in the position between the input and the output shafts. Whenever there is a discrepancy between the input and output, the spider shaft moves the outer-

Digitized by Google

contacts which control the action of the servo motor so that the motor drives the left side of the differential in the opposite direction to that taken by the input. Thus, the servo always drives to reduce the difference, or error, to zero.

A better understanding of the follow-up contact mechanism can be had from a study of figure 8–5. The outer contacts are movable and the double or inner contact is stationary (fig. 8–5A). Beneath this contact assembly is a small crank arm, attached to the differential spider shaft. At one end of the crank arm is a roller. In the normal position, the crank arm is horizontal, and a spring causes the base plate of the contact arm to bear against the roller holding the contact arm in a vertical position.

If the crank arm turns clockwise as shown in figure 8–5B, it rotates the outer contact arm clockwise opposing the action of the spring. This causes the left outer contact to make with the central contact, and the servo drives in a given direction. In C of the figure the arm is rotated counterclockwise; thus the roller no longer bears against the base of the contact arm, and the arm is rotated counterclockwise by the action of the spring. This brings the outer right contact against the center arm—the motor drives in the opposite direction.

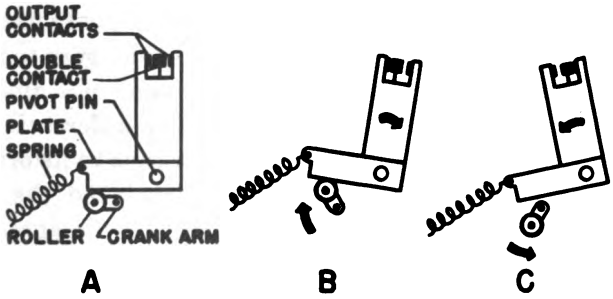


Figure 8–5.—Follow-up contacts.

Figure 8–6 shows a complete servo follow-up unit. The elements of a follow-up control are mounted so that the device will take up as little space as possible and may be installed rapidly at any point in the computer. This facilitates

Digitized by Google

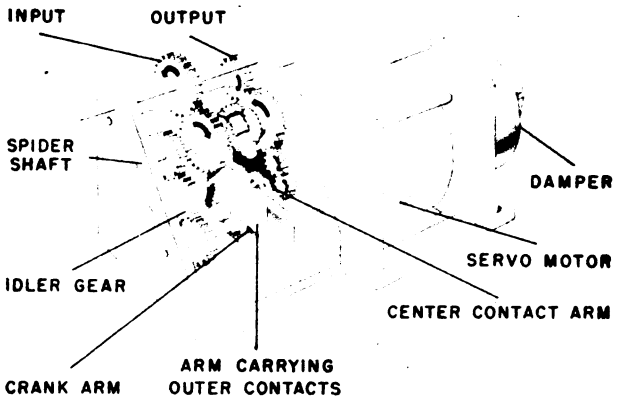


Figure 8–6.—A complete follow-up assembled.

easy maintanence. The follow-up assembly shown is not an actual unit—the gearing has been spread out for the sake of clarity. In this arrangement, the crank arm controlling the contacts is driven by the spider of the differential through an idler gear. This is the middle gear on the left side of the drawing. Other elements are easily added to this form of assembly permitting the most complete type of follow-up control. These will be discussed shortly.

The operation of this mechanism is the same as the simplified arrangement of figure 8–3. The input signal offsets the input side of the differential causing the spider gear to rotate and position the contacts of the servo motor in a given direction. The servo drives until the other differential side gear turns sufficiently to rotate the spider back to its original position—the contacts are then centralized and the servo stops driving; the output shaft position is now in agreement with the input shaft position.

Follow-Up Intermittent Gearing

The follow-up in figure 8–6 can be improved in two ways—by including intermittent gearing and a magnetic drag. A follow-up employing these refinements is shown in figure 8–7.

Digitized by Google

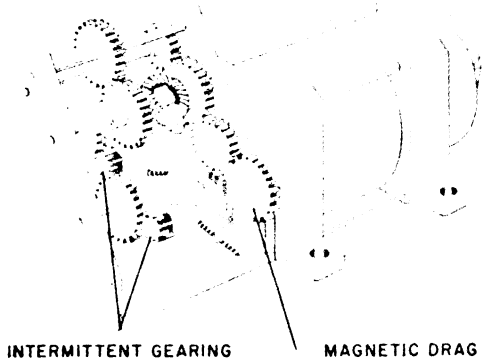


Figure 8–7.—A follow-up employing intermittent gearing and a magnetic drag.

Let's start by studying the intermittent gearing first. Do not confuse this mechanism with the intermittent drive, another basic unit.

The majority of the electro-mechancial follow-up controls now in use employ intermittent gearing. This type of gearing permits the input shaft to make many revolutions in relation to the shaft which carries the crank arm. Thus, an input signal may come into a follow-up control faster than the servo can convert it into an output. The extra input is "stored" in the intermittent gearing until the servo output can catch up. This gearing is so constructed that, while the input is driving continually, the output from the intermittent gearing drives a fixed small amount and then remains stationery. The input must turn a certain amount before the crank arm is moved again.

This arrangement is somewhat like fine and coarse control so often used in synchro transmission. Without the intermittent gearing the follow-up would do all right on small signals, but the crank arm would spin and make several revolutions on large, fast signals which would throw the input and output shafts permanently out of synchronization. This of course cannot be tolerated.

Digitized by Google

Going back to figure 8–7 again, the two disks near the left are identical and they each carry a 2-tooth sector gear. The two small gears which intermittently mesh with the 2-tooth gears are special 8-tooth intermittent gears. The large gear adjacent to the lower disk is a 40-tooth gear, and it is fixed to the shaft so that it turns whenever the lower disk turns. The intermittent 8-tooth gears turn two teeth for each revolution of the disks when engaged by the 2-tooth sector gears; notice that the detent in the two disks allow the intermittent gears to turn during these engagements. The intermittent gears are locked for all other positions of the disks.

A study of the gearing will disclose that 40 revolutions of the input shaft are taken to rotate the crank arm one-quarter turn—that's a reduction ratio of 160 to 1. Yet, for final positioning, the ratio is reduced to 40 to 8, or 5 to 1, during the times when the sectors are engaged with the intermittent gears.

Putting it another way, intermittent gearing enables the input to rotate 40 times, yet the correct contacts remain closed. It enables the servo to lag the signal momentarily without falling out of step. Also any input value coming into the follow-up control when the power is off is, in effect, stored up in the intermittent gearing until the servo is energized again and catches up with the input.

Magnetic Drag

The magnetic drag of the follow-up in figure 8–7 is shown in more detail in figure 8–8. Up to this point, for the sake of simplicity, the center arm has been indicated as fixed to the frame and stationary. In practice the center contact arm is mounted on a shaft which can be rotated, within limits, by a magnetic drag shown in figure 8–8.

When a magnetic drag is geared to the servo, the tendency of the motor to overrun the point of synchronism is counter-

Digitized by Google

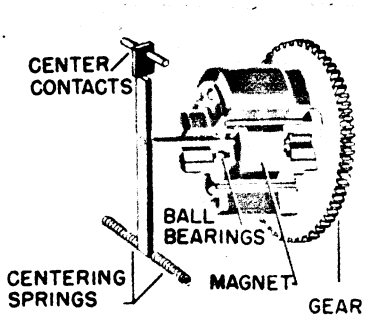


Figure 8–8.—Magnetic drag cut-away view.

acted in such a manner that the oscillations are greatly reduced, resulting in the motor being brought quickly to rest at the point of zero error. The magnetic drag consists of two major parts: a frame, and a magnetized core. The operating principle underlying the magnetic circuit is similar to that of the magnetic servo damper shown in figure 8–2. A study of the gearing in figures 8–7 and 8–8 will show that, when the motor runs in one direction, the drag tends to offset the center contact arm in the opposite direction by an amount proportional to the servo speed. This causes the center contact to break the connection with the outer contact before the motor reaches the point of zero error or synchronism. The action of the crank can therefore be said to anticipate the point of synchronism, causing the contacts to be separated before the point of zero error is reached. Then, since inertia causes the rotor to coast, the magnetic drag pulls the center arm against the opposite contact causing the motor magnetic field to reverse just before the point of synchronism is reached. This creates a braking action. When the motor runs through correspondence, the opposite outer contact is brought to bear on the center contact causing the motor to reverse its rotation. The magnetic drag now performs the same function, only in the reversed direction. The drag

Digitized by Google

again anticipates the point of synchronism by breaking the contacts and slowing the motor prematurely.

Since the speed of the motor is diminished considerably at each overdrive cycle, the amount the center contact arm is rotated at each cycle is considerably diminished also. In other words, the size of the oscillations diminish rapidly, and the motor is quickly brought to rest at the point of synchronism.

THE COMPENSATED FOLLOW-UP CONTROL

It has been shown that the magnetic drag helps to bring the servo motor to rest at the point of synchronism by offsetting the center contact arm. In doing this job, however, the drag gives the follow-up certain characteristics which cannot be allowed in some applications. The drag offsets the center contact arm by an amount which is proportional to the speed at which the motor drives. This does not introduce an error as long as the signal is constant and the powered

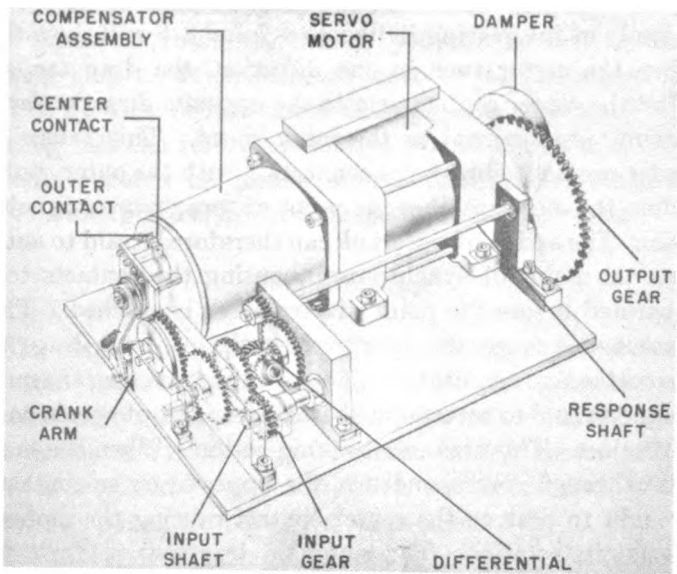


Figure 8–9.—The compensated follow-up control.

Digitized by Google

shafting is being turned at a constant speed. But when the follow-up has to follow a signal which keeps fluctuating, conditions change; the magnetic drag keeps the center contact offset. Thus, the magnetic drag method is not adaptable where the output must closely follow the input.

It was also stated that the intermittent gearing of the follow-up just described would allow the output to lag the signal. In other words, the output value will not read exactly the same as the input value at any given instant. This lag error can be ignored in some applications, but not in all. To eliminate this error the compensator mechanism now to be discussed is included in the follow-up control, and a unit which has such a mechanism is known as a compensated follow-up. This device is shown in figure 8–9.

This type of follow-up control is easily recognized by the round grey housing attached to one end of the servo motor. The housing contains a compensator mechanism consisting of a magnetic drag and special type differential equipped with an inertia weight. A detailed drawing of this unit is shown in figure 8–10.

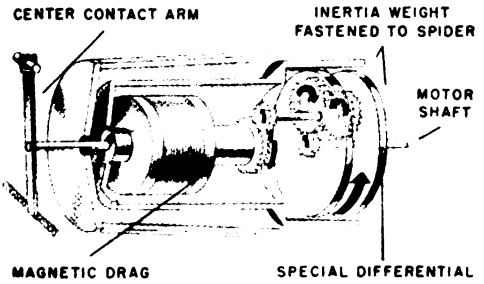


Figure 8–10.—Compensator mechanism.

It was previously stated that the use of a magnetic drag introduces a lag error between the input and the output of a follow-up control while the signal is changing, and that such an error becomes too great to be permitted when a signal comes in at a high velocity. This lag error is eliminated by the compensator which consists of a magnetic drag and

Digitized by Google

an inertia weight, both of which are driven by the servo motor through a differential. The motor drives one side of the planetary-gearing type of differential, and the magnetic drag is driven by the other side gear. The spider of the differential is attached to a comparatively heavy case to form the inertia weight as shown in figure 8–10.

When the servo motor starts to drive, the inertia weight tends to remain at rest. One side of the differential rotates the frame of the drag, and this rotation causes the drag frame to be coupled to the drag magnet by a magnetic force coupling. The magnetic force coupling applies a torque to the drag magnet, and since the magnet cannot be pulled around more than a few degrees due to the contact springs, there is a resistance to the rotation of the drag frame. This being so, the other side of the differential must drive with an equal force. And since there is nothing holding the inertia weight case and plates stationary, this force starts the weight rotating. The inertia weight gathers speed and, if the servo motor continues to drive at a constant speed, it quickly approaches the speed of the motor.

Now, the total output of the differential can only equal the input—the speed of the drag frame plus the speed of the inertia weight can only equal the speed of the motor. Therefore as the inertia weight gains speed the drag frame must lose speed. This it does, until it almost stops. As the drag frame loses speed, the torque exerted on the drag magnet decreases. Immediately, the centering springs act to bring the center contact arm back to its center position, and the contact assembly comes back to the position of zero error. Therefore, even though a signal is fluctuating about a given speed, this follow-up control will operate without lag error. In a few words, the dynamic accuracy of the compensator follow-up far exceeds that of the follow-up described in figure 8–7.

SYNCHRO FOLLOW-UPS

Although synchro motors transmit extremely accurate signals, their outputs must be boosted considerably before

Digitized by Google

they can drive heavily loaded shafts. The reason is that the torque delivered by a synchro falls off sharply as the rotor approaches the point of synchronism. As the rotor nears the point of zero error, the induced current in the stator coils is rapidly reduced, seriously affecting the ability of the synchro to drive a heavy load. At the point of zero error the torque becomes zero.

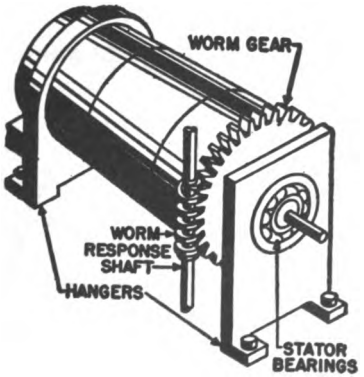


Figure 8–11.—Mounting of a bearing mounted synchro.

From your previous study you will remember that the bearing mounted synchro is electrically the same as ordinary synchro motors and generators; but mechanically the bearing mounted synchro is different. It's designed to receive a regular electrical signal in the stator which is imparted to the rotor in the usual manner, and also to receive a mechanical signal at the stator. Look at figure 8–11 and notice the ball bearings which mount the synchro stator so that it can be turned mechanically. Also notice the response shaft and gearing. This response shaft turns the stator—the response shaft delivers the mechanical signal to the stator. You will recall that, with the stator being bearing mounted, the stator leads must be brought out to slip rings and brushes so that the stator can be turned.

Bearing mounted synchros are usually used to operate a set of electrical contacts. Then the contacts control a servo

Digitized by Google

motor like the one in figure 8–1. The servo drives whenever the synchro closes the contacts. Thus the servo actually drives out the synchro signal. You are probably wondering why the synchro does not drive out the signal directly. The reason is simple; the loads are fairly heavy and the synchro doesn't have enough torque to drive them. So the synchro controls a servo, and the servo does have sufficient torque to drive the loads—the servo does the work for the synchro.

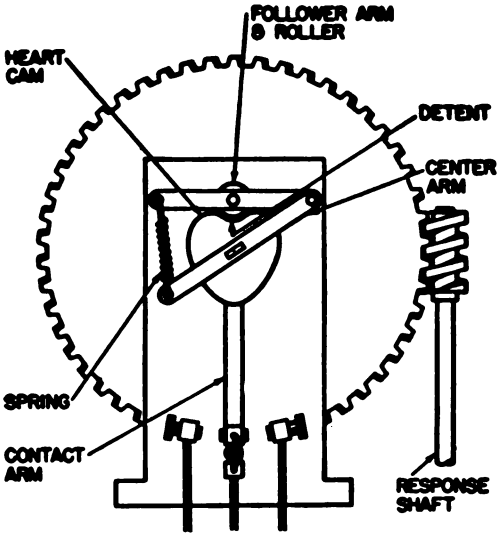


Figure 8–12.—Bearing mounted synchro electrical contacts.

Look at figure 8–12 to see how the bearing mounted synchro controls the servo contacts. Notice the response shaft. This response shaft is turned by the servo—it rotates the synchro stator as the servo rotates. Now, find the heart cam and contact arm. The contact arm is secured to the heart cam. But both the arm and cam are ball bearing mounted on the rotor shaft; neither the contact arm nor the cam turns directly with the rotor shaft. Next, notice that the center arm is secured to the rotor shaft (do not confuse this with the contact arm). This center arm drives the follower arm and

Digitized by Google

roller. The spring keeps the roller in the detent of the heart cam.

You are probably wondering why the contact arm is driven by the heart cam assembly. Here is the reason—a large electrical signal turns the synchro rotor with considerable torque. The torque closes the contacts at the contact arm. Then, as soon as the contacts are closed, the spring stretches and the roller gently rolls out of the detent. This frees the rotor so that it can follow the signal. Without the heart cam, the rotor would continue to drive against the closed contacts. This might damage the contacts or throw the rotor itself out of line. There is another reason for the heart cam drive—without the drive, a power failure at the servo would interrupt the response drive and hold the rotor out of correspondence. Excessive currents would therefore continue to flow in the stator windings which might damage them. But with the heart cam drive, the roller rolls out of the detent and allows the rotor to turn to correspondence with the electrical signal.

Now, imagine an electrical signal is received and the synchro rotor turns clockwise. The contact arm is then

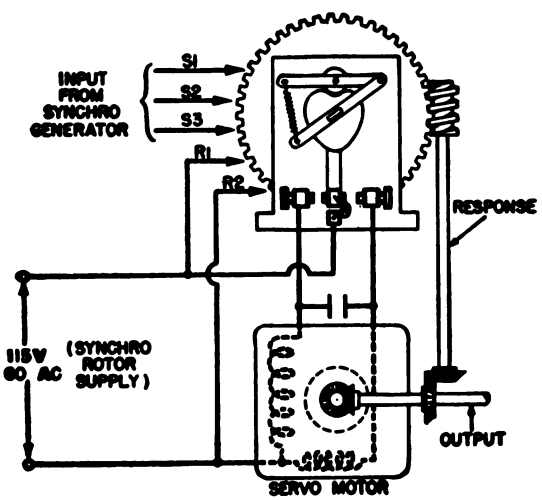


Figure 8–13.—Simplified synchro follow-up.

Digitized by Google

caused to touch the left hand outer contact. This causes the servo to drive and rotate the stator counterclockwise in response. Of course, the rotor is carried with the stator and, in turn, the center contact arm is rotated counterclockwise. The counterclockwise motion of the contact arm breaks the contact with the left side and the servo stops driving. The synchro follow-up and servo motor are shown in figure 8–13.

Summing up, the electrical signal is fed to the bearing mounted receiver via S1, S2, and S3. This signal turns the receiver rotor—in the direction corresponding to the signal. The turning rotor drives the heart cam to close the proper set of servo contacts. The servo drives in the direction of the signal. As the servo drives, it does two things. First, the servo drives out the signal at its output shaft with sufficient torque to position a comparatively large load. And second, the servo drives the synchro stator and rotor in response. When the response equals the signal, the contacts open and the servo stops.

Single Speed Synchro Follow-Up

The synchro follow-up just described is not a complete system in that the servo must be damped by means of a contact control like the magnetic drag or the compensated follow-up.

A photograph of a single speed follow-up is shown in figure 8–14. The contacts controlling the action of the servo are similar to those of the follow-up control you studied earlier. The two outer contacts are fixed on an arm which can be rotated. The center contact is mounted on an arm attached to the rotor of a magnetic drag which is driven by the servo. The drag is used here in the same way and for the same reason as in the follow-up you studied back in figure 8–7.

To understand how these contacts are controlled, first assume that the outer contact arm is fixed to the rotor shaft of the synchro motor. Also, assume that the rotor has turned in response to a transmitted signal until one outer contact

Digitized by Google

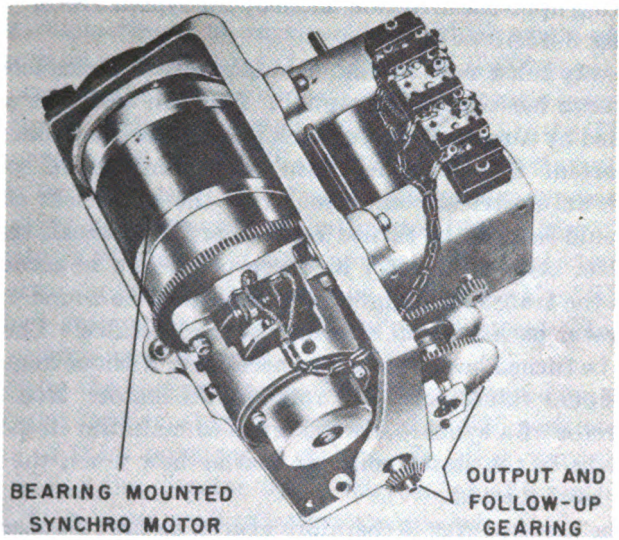


Figure 8–14.—Single speed synchro follow-up.

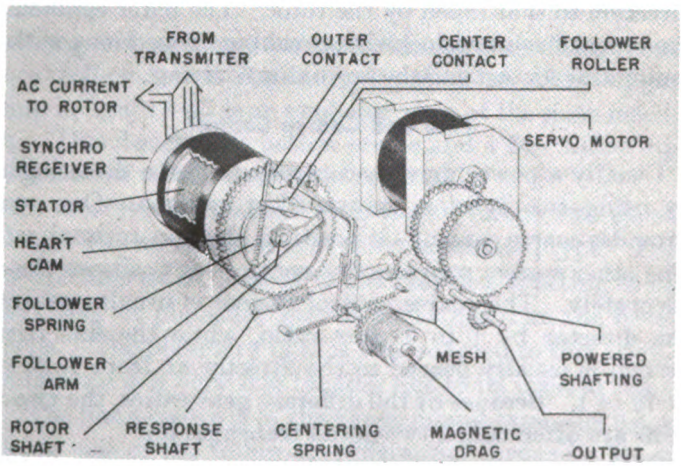


Figure 8–15.—Simplified drawing of single speed follow-up shown in figure 8–14.

Digitized by Google

or the other is brought against a center arm contact—depending upon the direction taken by the synchro rotor. (Follow fig. 8–15.)

A way must now be found to separate the contacts once the servo has obeyed the signal. This can easily be accomplished by turning the rotor back in the direction from which it started. For example, if the rotor were turned so as to make an electrical connection with the outer left contact, it would have to be turned back in order to break the connection. Since the rotor has been positioned in accordance with the transmitted signal, a means must be found to turn the rotor back without altering the signal value. The rotor may be turned back as much as necessary, without disturbing the signal value, simply by rotating the stator. Remember, the rotor of a synchro always tends to maintain its position relative to the stator coils, no matter how much the stator may have rotated.

The motor stator is therefore geared to the response shaft of the servo, and the whole stator is rotated in the opposite direction to that taken by the rotor. The outer contacts are thus turned counterclockwise, breaking connections with the center arm contact and the servo stops driving.

Fine and Coarse Control

Usually a power drive is controlled from a directing unit by using two synchro transmitting systems. One system provides coarse control—it positions the gun approximately. The other system provides fine control—it positions the gun accurately. The coarse control system is usually geared to the director by 1 to 1 gear ratio, while the fine control system is usually geared to the director at 18 to 1, 36 to 1, or 72 to 1. Because of the different gear ratios, the two systems are often called two-speed transmission.

Stop a moment and review the reasons for two-speed transmission. Suppose that a synchro transmitter is geared directly to a director, and it has a total error of 36 minutes—due to gearing and electrical inaccuracies. This means that

Digitized by Google

each transmitted signal may have an error of as much as 36 minutes. This would result in the director and gun being as much as 36 minutes out of correspondence which would cause an error in train of 360 yards for a range of 10,000 yards.

This error can be reduced by making the gear ratio between the synchro and the director 36 to 1 instead of 1 to 1. Then the synchro would revolve 36 times for each revolution of the director. And each revolution of the synchro represents only 10 degrees of movement of the director ($360° \div 36 = 10°$). The synchro's 36 minutes of error now represents only 1 minute of error in the director position ($36' \div 36 = 1'$). Thus the 36 to 1 gearing has reduced the error 36 times. This is the fine or high-speed control.

Obviously the coarse synchro control is required to prevent the gun from synchronizing at any one of 36 positions—only one of these positions is correct. In other words the gun could lag the director by 10 degrees, or any multiple thereof, if the coarse synchro were not employed.

Two Speed Synchro Follow-Up Control

A photograph of one of the most commonly used two speed synchro follow-ups is shown in figure 8–16. The upper drawing in figure 8–17 is an exploded view of the same mechanism. This design uses both a coarse and a fine follow-up control, each of which is operated separately.

There are several familiar components in the two speed follow-up: The servo motor is of the compensated type. The follow-up differential located in the response shafting is of the spur gear or planetary gear type, rather than the bevel gear type. The planetary gear is best adapted to this application because it is very free turning due to its jeweled bearings. The fine synchro is of the flange mount type—its rotor drives one side of the follow-up differential through a heart cam arrangement. The coarse synchro is of the ball bearing mount type—its rotor positions the coarse control contacts mounted on the scissor arms.

Digitized by Google

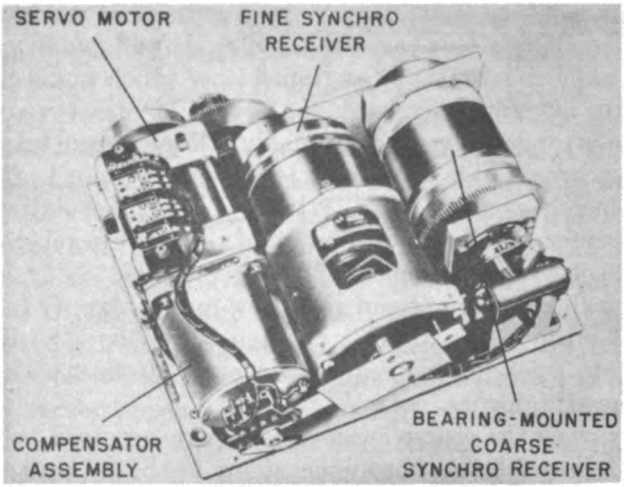


Figure 8–16.—Two speed synchro follow-up.

Before going through the operation of this mechanism, let's first study the electric circuit shown in the lower right hand drawing of figure 8–17. Notice that the servo can be controlled by either the fine or coarse contacts. During the times when the synchros are within about two degrees of correspondence, the fine synchro has control; the coarse contacts are centralized. However, when the follow-up output is sufficiently out of correspondence, the scissor arms are forced to spread, opening the upper contacts which disconnects the fine center contacts from the power supply. The coarse synchro then has control. Notice the scissor arm is shown by dotted lines in the lower right hand drawing of figure 8–17.

Let's now study the function of the mechanism shown in the upper drawing of figure 8–17. The stator of the fine synchro motor is mounted rigidly in a fixed position, while the rotor drives a heart cam assembly to rotate one side of the spur gear differential. The spider of the differential is driven by the servo motor. The differential output therefore represents the difference between the input received by the fine synchro and the output from the servo motor. The

Digitized by Google

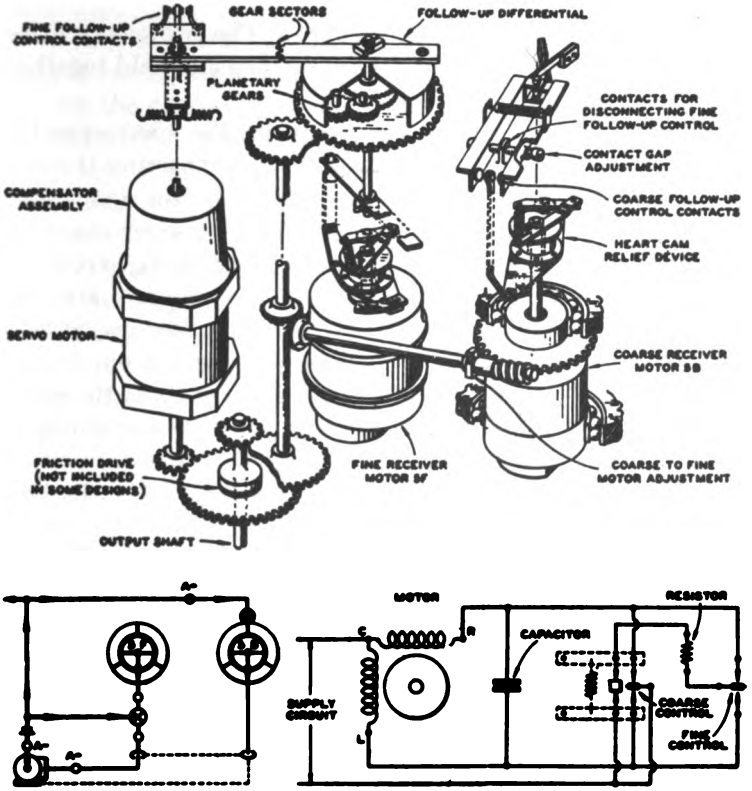


Figure 8–17.—The upper drawing is an exploded view of the two speed synchro follow-up shown in figure 8–16; lower left hand drawing shows elementary schematic; lower right hand drawing shows wiring diagram.

differential output moves a gear sector meshing with an arm carrying the two outer fine control contacts. The inner contact arm is moved by a compensator assembly.

The stator of the coarse synchro is rotated by the servo motor, while the rotor is used to position a heart cam assembly and, in turn, the inner contact arm of the coarse follow-up control. For a given signal the servo rotates the stator in the direction opposite to that of the rotor. This produces a movement of the inner contact arm proportional to the difference between the servo motor output and the

Digitized by Google

signal received by the coarse synchro. The two scissor arms of the coarse follow-up control are pivoted and held together by the pressure of the spring.

Each scissor arm carries two contacts; the lower ones for coarse control and the upper ones for disconnecting the fine follow-up controls. The distance between the two outer arms can be adjusted by means of the two upper contacts. If the inner contact arm is displaced sufficiently from its central position, it moves one of the outer contact arms to spread the scissors and disconnect the fine follow-up control. At the same time, the inner contact arm against one of the two lower control contacts controls the operation of the servo motor. For small differences between the servo motor output and the received signal, the inner contact arm will move in the gap or dead space between the two outer contacts, and the fine follow-up control will regulate the servo motor.

Go back to figure 8–16 and locate the resistor at the lower right-hand side of the photograph; this resistor is also shown in the wiring diagram of figure 8–17. Since the inner contacts of the coarse follow-up control touch a control contact before disconnecting the fine follow-up control, a condition arises where both windings of the servo motor are connected directly to the power supply, resulting in temporary loss of control. This effect is avoided by inserting a resistance in series with the fine center contact so that the coarse follow-up, operating at a higher voltage, will actually take over control of the servo motor. The resistance also aids in reducing sparking at the fine contacts.

The two-speed synchro follow-up can easily be adjusted by the following procedure. Make reference to the adjustment points marked A in the lower left hand schematic of figure 8–17.

First put the fine synchro on electrical zero—a voltmeter method works well here. With the fine synchro on electrical zero, turn the motor shafting to centralize the fine contacts. Wedge the servo motor shafting at its zero position being careful not to disturb the contact position.

Digitized by Google

With the coarse synchro on electrical zero, centralize the coarse contact by slipping the worm gear on the shaft which drives the coarse synchro. This adjustment can be seen in the exploded view drawing of figure 8–17, and in the elementary schematic. Once the setting has been made, tighten this clamp.

Remove the wedge from the motor shafting.

Energize the servo motor. It will synchronize at zero. With both synchros on electrical zero and the servo motor energized, loosen the clamp at the servo output shaft and turn the dial or counter to zero. Tighten the clamp on the servo shaft. This clamp adjustment is located just above the servo motor in the elementary schematic of figure 8–17.

QUIZ

1. The direction of rotation of the servo motor is controlled by a single pole, double throw switch. The switch selectively connects the
   - (*a*) capacitor in series with one winding or the other.
   - (*b*) capacitor in parallel with the running winding.
   - (*c*) starting coil in series with one winding or the other.
   - (*d*) starting coil in parallel with one winding or the other.
2. The magnetic damper is used to directly damp the
   - (*a*) inner servo control contact arm.
   - (*b*) servo motor rotor.
   - (*c*) outer servo control contact mechanism.
   - (*d*) servo follow-up differential.
3. Which of the following statements for the magnetic damper is false?
   - (*a*) The rotor is a permanent magnet.
   - (*b*) The case is made of brass.
   - (*c*) The heavy steel ring is laminated.
   - (*d*) The copper rings help distribute current evenly in the steel ring.

Do you know the purpose of the component parts of a basic servo follow-up? Select from column B the item which completes the sentence of column A.

Digitized by Google

Column A	*Column B*
4. Differences in error are measured by the	(*a*) outer servo contacts.
5. The magnetic damper damps the	(*b*) inner servo contacts.
6. Error is reduced by driving of the	(*c*) side gear.
7. The input signal positions a	(*d*) spider gear.
8. The differential spider positions the	(*e*) servo rotor.
	(*f*) differential.
	(*g*) servo motor.

9. Which of the following statements pertaining to the follow-up differential, as found in a servo follow-up, is false?
   (*a*) One of the side gears is positioned by the input.
   (*b*) The response of the servo positions one side gear.
   (*c*) When the side gears have been rotated equal amounts in opposite directions the contacts are centralized.
   (*d*) The spider gear positions the inner servo contact arm.
10. Which of the following statements pertaining to the intermittent gearing is false?
   (*a*) The gearing "stores" the input signal until the servo can catch up.
   (*b*) The intermittent gearing facilitates a high sensitivity for the final positioning of the output shaft.
   (*c*) The intermittent gearing improves the dynamic accuracy.
   (*d*) The intermittent gearing allows the servo to lag the high-speed signals momentarily without falling out of step.
11. The magnetic drag damps the
   (*a*) servo directly.
   (*b*) inner servo contact arm.
   (*c*) differential spider.
   (*d*) outer servo contact arm.
12. Which of the following statements pertaining to the magnetic drag is false?
   (*a*) It damps the outer contacts.
   (*b*) It damps the inner contacts.
   (*c*) It anticipates the point of synchronism by breaking the contacts prematurely.
   (*d*) It displaces the center contact by an amount proportional to the servo speed.
13. The compensator mechanism of the compensated follow-up
   (*a*) improves the dynamic accuracy.
   (*b*) introduces a lag error for high-speed signals.
   (*c*) regulates the applied voltage strength to the servo motor.
   (*d*) balances out the error caused by the spur differential.

Digitized by Google

14. One of the following statements regarding the ball bearing mounted synchro is false—which one is it?
    (*a*) The rotor is driven by the response of the follow-up motor.
    (*b*) The rotor and stator electrical connections are brought out to slip rings.
    (*c*) The response of the servo positions the stator in follow-up.
    (*d*) The signal is always indicated as rotor position relative to the stator coils.
15. In the single speed synchro follow-up the
    (*a*) use of the bearing mounted synchro makes the use of a differential necessary.
    (*b*) response is geared to the synchro rotor.
    (*c*) magnetic drag damps the inner contacts.
    (*d*) heart cam centralizes the outer contact arm relative to the synchro stator.
16. If the gear ratio between a synchro and a director is made 18 to 1 instead of 1 to 1, the error between the positions of the director and gun may be reduced as much as
    (*a*) 144 times.
    (*b*) 72 times.
    (*c*) 36 times.
    (*d*) 18 times.
17. If a 5 minute error in gun train causes a 7.3 yard error at 5,000 yards, the error at 12,000 yards will be
    (*a*) 36.5 yards.
    (*b*) 29.2 yards.
    (*c*) 21.9 yards.
    (*d*) 17.5 yards.
18. In the two-speed synchro follow-up, which of the following positions the outer fine control contacts?
    (*a*) Differential side gear.
    (*b*) Servo rotor.
    (*c*) Compensator assembly.
    (*d*) Differential spider.
19. In the two-speed synchro follow-up, the point where the coarse synchro takes over from the fine synchro can be controlled by adjusting the
    (*a*) coarse to fine adjustment.
    (*b*) upper contacts on the scissor arms.
    (*c*) scissor arm spring tension.
    (*d*) follow-up differential coupling.

Digitized by Google

20. When the fine synchro of the two-speed follow-up has control, the
    (*a*) coarse synchro is deenergized.
    (*b*) roller of heart cam relief device is out of the detent.
    (*c*) coarse control contacts are near centralization.
    (*d*) resistor in series with the fine center contact is shunted.

Digitized by Google

CHAPTER 9

SOLVING WIND CORRECTIONS

AIR IN MOTION

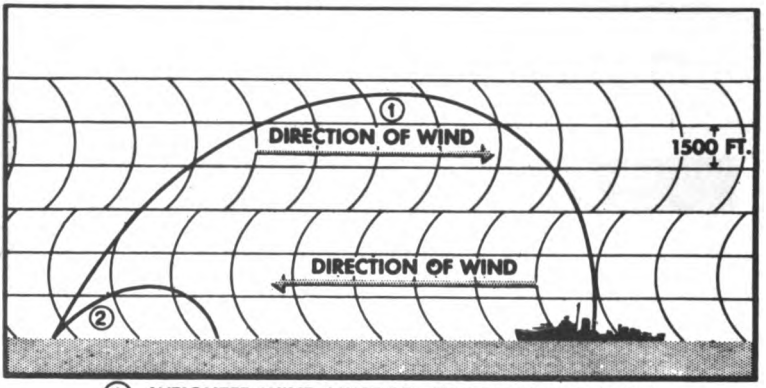
At best, corrections for wind are only approximate because not only does the density of air change at different heights, but its motion also changes at various levels. For instance, the wind might be blowing from the north on the surface of the ocean, and from the south at some higher level. You can see a typical situation in figure 9–1.

If there's an aerological party abroad, an investigation of wind conditions at different elevations is made either by aloft observations from an airplane, or by observing the movements of a small balloon. The balloon's course is plotted as it proceeds upward through the 1,500-foot bands shown in figure 9–1 so that wind direction and speed at each level may be evaluated.

After the wind at various levels has been weighted (corrected for air-density changes), a resultant or BALLISTIC WIND is calculated by the method set forth in figure 9–2. A plot of the weighted winds is to scale, and the over-all wind angle *Bw* and wind speed *Sw* determined. *Bw* is measured in degrees, and *Sw* is measured in knots. These values are then set into the computer to enter into the computations of gun orders.

When aloft observations are not possible, the wind must be observed at surface level. This is admittedly an inac-

Digitized by Google



① WEIGHTED WIND MUST BE USED TO BE ACCURATE

② SURFACE WIND ACCURATE ENOUGH

Figure 9–1.—Winds at various altitudes.

curate way to find the angle and speed of wind, but it's better than nothing.

Making wind allowances is further complicated because in the upper air winds blow up and down as well as horizontally. These vertical winds can either lift the projectile or push it down which would lengthen or shorten the range. This effect is never considered in fire control problems.

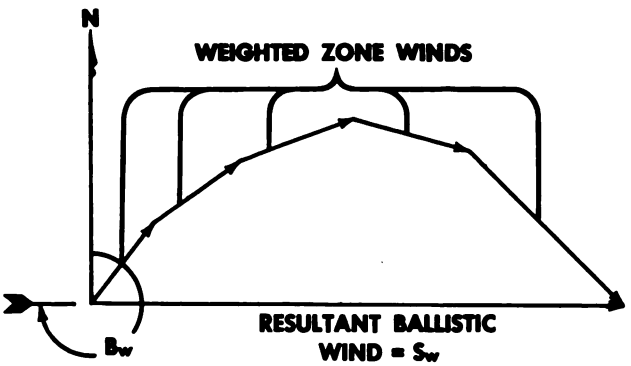


Figure 9–2.—Ballistic wind.

Digitized by Google

CROSS WIND

Every ship at sea is influenced by wind, blowing from some direction of the compass. Except during a hurricane or some other unusual disturbance, this is always a single wind. However, regardless of where the wind is blowing from, the important thing is the angle it makes with the line of fire (LOF). It is easy to realize that if the wind is blowing directly across the LOF it will deflect the projectile one way or the other, and if the wind is blowing along the LOF it will speed up or slow down the projectile. But the wind is never so accommodating as to blow directly across or along the LOF—instead, it usually blows at some other angle.

Even so, it is necessary to figure out how much the wind will affect the RANGE and DEFLECTION of the projectile, and apply the necessary corrections to the gun position. It is obviously much easier to take a single wind and think of it as two component winds, one blowing across, and the other along, the LOF. Then you can take the cross-wind component and compensate for it by a correction to sight deflection

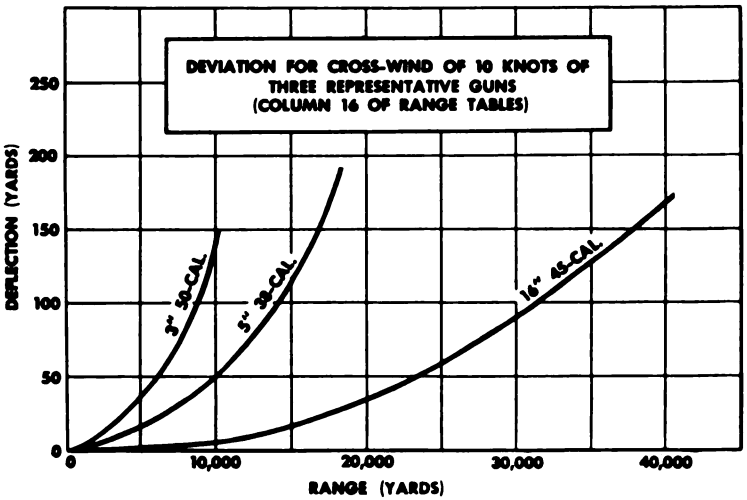


Figure 9–3.—Cross-wind curves.

Digitized by Google

(Ds), and the range-wind component (component blowing along LOF) and compensate for it by a correction to sight angle (Vs).

This explains why, in actual practice, wind blowing at AN ANGLE to the LOF is resolved into components along and across the LOF, and is corrected for as though you were dealing with two individual winds.

Let's study the two wind components separately. Cross wind is considered separately from drift, and is added to sight deflection as an individual correction. To get an idea of the significance of cross wind, look at the curves for three representative guns in the graph of figure 9–3. These curves show the lateral deviation of the projectile in yards for a cross wind of 10 knots. These curves were plotted from column 16 of the range tables for each gun.

It is interesting to notice that the cross wind deflects the projectile more and more as range increases. When the shell is first fired, it is traveling so fast that the wind has little chance to affect it. But as the projectile starts losing speed the wind begins to deflect it to a marked degree. That is why the curves in the graph sweep upward as the ranges increase. Obviously, the effect of cross wind varies as a function of range, rather than directly with range.

Looking at it another way, you will see that the amount the projectile deflects will be dependent on two things: wind speed (Sw), and the length of time the wind acts on the projectile.

That brings up time of flight (Tf). You can see that Tf represents the total time the wind acts on the projectile—the same time it takes for the shell to reach the target. Also, from your study of science, you'll recall that distance is equal to speed multiplied by time. And so your first thought is that the total deflection of the projectile will be equal to $Tf \times Sw$. You would be on the right track, but a little incorrect because the projectile won't deflect at the same speed that the wind is blowing.

The equation can be modified and made correct by multi-

Digitized by Google

plying by a small constant (k) whose value (which will vary as the range changes) is dependent on the shape and weight of the shell. Now you can say that the total deflection distance, as a result of cross wind, will be

$$k \times Tf \times Sw.$$

This formula is not much good unless you modify it a bit more. First, you want to convert it to yards deflection at the target. Since Sw is in knots, you multiply it by 0.563 to convert it to yards per second. Then: $Sw \times 0.563 =$ yards/sec. (see fig. 9–4). This can be done by a gear ratio. For instance, a 2:1 gear ratio reduces the input by one half, which is the same as multiplying the input by 0.5.

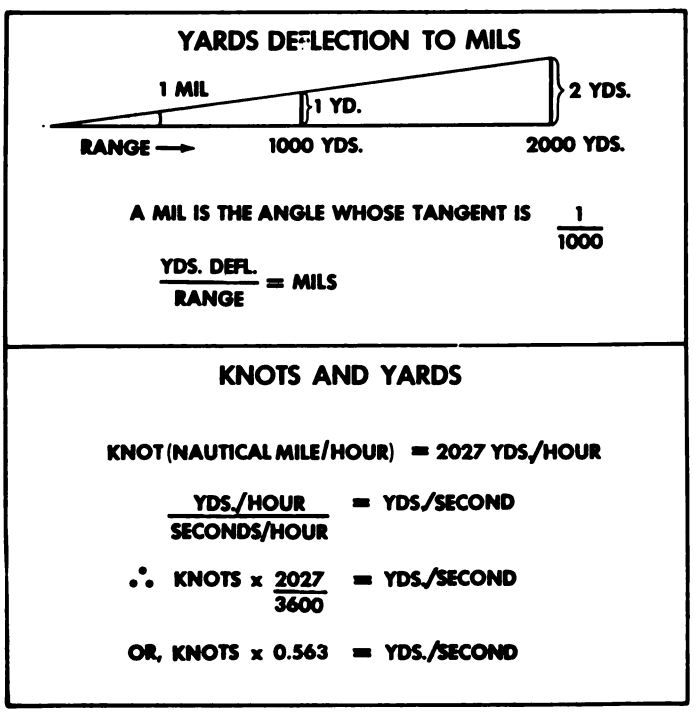

YARDS DEFLECTION TO MILS
1 MIL
1 YD.
2 YDS.
RANGE
1000 YDS.
2000 YDS.
A MIL IS THE ANGLE WHOSE TANGENT IS 1/1000
YDS. DEFL. / RANGE = MILS
KNOTS AND YARDS
KNOT (NAUTICAL MILE/HOUR) = 2027 YDS./HOUR
YDS./HOUR / SECONDS/HOUR = YDS./SECOND
∴ KNOTS x 2027/3600 = YDS./SECOND
OR, KNOTS x 0.563 = YDS./SECOND

Figure 9–4.—Mils, knots, and yards.

Digitized by Google

Next, to get the distance deflection in yards (linear deflection), you multiply Sw by time (in this case, Tf). Now you have

$$\text{linear deflection due to wind} = k\ (Tf \times Sw \times 0.563) \text{ yards.}$$

This last formula gives you the yards deflection at the target, but before it can be used to correct sight deflection (Ds), it must be converted to angular measure, or mils. The table in figure 9–4 tells you how. Simply divide yards deflection by range.

The angular deflection due to wind—ANGULAR WIND DEFLECTION, Dw—now becomes

$$Dw = \frac{k \times Tf \times Sw \times 0.563}{\text{Adv. Range}}.$$

Notice that you use ADVANCE RANGE, $R2$, the range to the

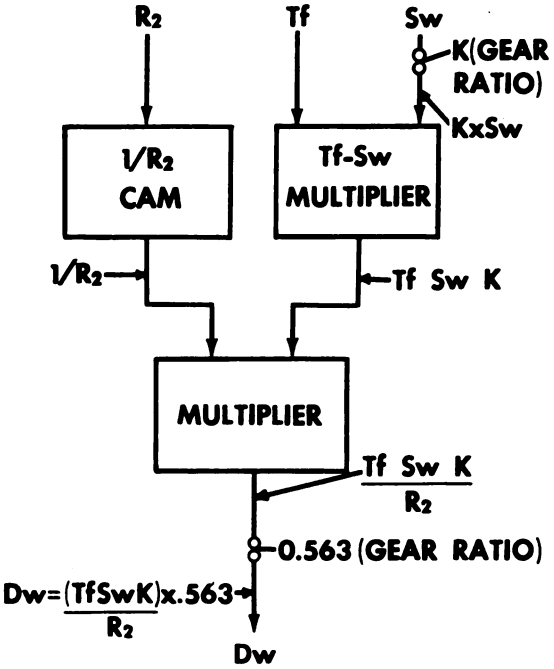


Figure 9–5.—Solving Dw.

Digitized by Google

future target position. This corrects the gun in the line of fire as desired.

Let's stop right here and see what can be done to solve the equation for *Dw* by the use of the basic mechanisms you studied in earlier chapters. Looking over the equation you will immediately decide that the two constants—*k*, and 0.563—can be handled by gear ratios. Also, you may decide to multiply *Tf* and *Sw* in a multiplier. So far, so good. But now you still have to divide by *R2*. You scratch your head a moment, and come up with an answer requiring a reciprocal cam and another multiplier. That gives you a set-up like the one in figure 9–5.

This arrangement would work fine, but it would be entirely too bulky and expensive. In order to cut down on the number of computing units, rangekeepers sometimes use a *Tf/R2* cam which is a combination of the reciprocal cam and *Tf* cam. This eliminates the use of one multiplier, to give you the set-up shown in figure 9–6.

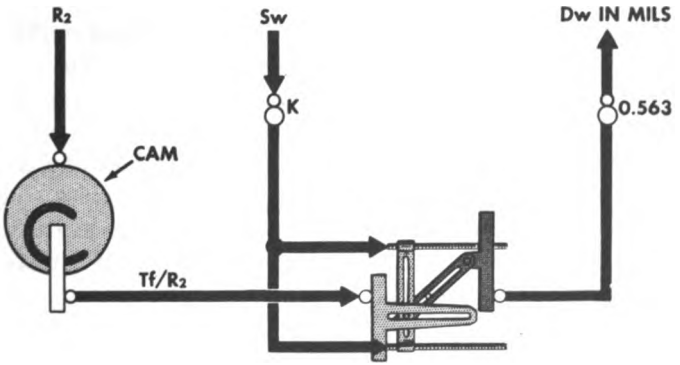


Figure 9–6.—Solving Dw with a cam and multiplier.

R2 rotates the *Tf/R2* cam; *Tf/R2* is taken from the cam follower to position the input rack of a screw-type multiplier.

Sw (in this case, the cross-wind speed in knots) is multiplied by *k* in a gear reduction, and it positions the screws and input slide of the multiplier.

Digitized by Google

The position of the output rack is proportional to the product $Tf/R2 \times Sw \times k$, which is then multiplied in another gear reduction by 0.563 to give you Dw in mils.

Since all ballistics are functions of advance range and advance elevation (range and elevation of future target position), many shortcuts are performed to eliminate the use of extra gear. The object is to use the minimum of parts. For instance, rather than computing $Tf/R2$ in a cam, it is usually made from other quantities which already exist in the machine. This of course, would further simplify the Dw computer in figure 9–6. You'll see many of these arrangements when you study actual gear.

If you go back and look over the curves in figure 9–3, and think about the constant k, you'll find it reasonable that k should vary with range. At long ranges k grows larger, because as the projectile slows down, the wind has greater effect. Experimentation has shown that as range quadruples, k approximately doubles for medium ranges.

Theoretically the correct way to handle the wind computation would be to get values of k from a cam and multiply these values, in a multiplier, by the output of a $Sw \times Tf$ multiplier. But, here again this would entail the use of an extra cam and multiplier.

One way to get around calculating exact values of k is to approximate it by a trick involving Tf. Tf varies something like k because it increases faster than range at the end of the trajectory where the shell slows down. So, instead of k, another expression can be used—

$$K1 - \frac{K2}{Tf}.$$

The second term will be small at long ranges and large at short ranges. Therefore, the total expression will be LARGE at long ranges and SMALL at short ranges as desired. By choosing the right values for the constants $K1$ and $K2$, you can make this expression nearly equal to the true value of k for all practical ranges. This new value for k is simply substituted in the basic formula $k \times Sw \times Tf$. You'll see

Digitized by Google

how it is worked mechanically when you study range wind later in this chapter.

Another approximate method used to calculate Dw in rangekeepers tackles the problem in a little different way. It takes even fewer mechanical devices to solve it. A study of the range tables, graphs, and curves has shown designers that both k and $Tf/R2$ vary alike with range—as range increases they, too, increase, only faster. It was found that they change in the same proportion as the square root of range. That is, as stated before, when range quadruples, k and $Tf/R2$ nearly double. Or, stating it mathematically,

$$k = K1 \times \sqrt{R2}, \text{ and } Tf/R2 = K2 \times \sqrt{R2}.$$

Here two entirely new constants, $K1$ and $K2$, are chosen to make the two expressions as nearly correct as possible.

When these values for k and $Tf/R2$ are substituted in the basic formula ($k \times Sw \times Tf/R2$), you get—

$$K1 \times \sqrt{R2} \times Sw \times K2 \times \sqrt{R2}.$$

Simplifying this expression gives

$$Dw = K \times Sw \times R2$$

where K is equal to $K1 \times K2$. A single multiplier and a gear ratio like that in figure 9–7 can work this out.

The basic idea to get straight is that fire control instruments use the minimum number of parts, and manufacturers

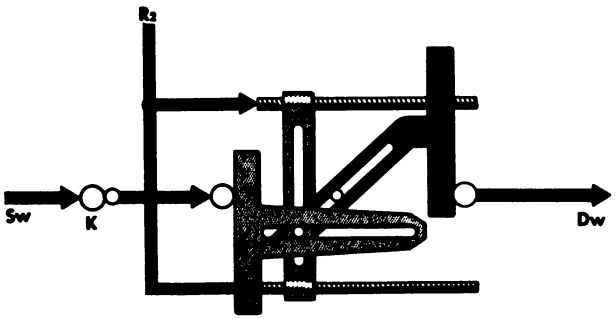


Figure 9–7.—Another method of calculating Dw.

Digitized by Google

have gone to great lengths to figure out ways of getting a solution from close approximations.

EFFECT OF RANGE WIND

The corrections for range wind are similar to those for cross wind, and are solved in much the same way. Range wind blows parallel to the LOR, either with or against the motion of the projectile, and gives a forward or backward velocity to it, which is independent of other motions. This velocity will equal $k \times Sw$, and will be moving the projectile throughout the time Tf. The value of k, of course, will not be the same at a particular range as for cross wind, because the wind will be acting on different surfaces of the projectile.

Here again, the computation for a 10-knot range wind has been performed for you in the range table. When plotted, these values will give you a set of curves similar to those for cross wind in figure 9–3.

Unlike cross wind, corrections for range wind are applied to advance range, as the name might imply. Therefore, the correction would be measured in yards rather than in mils. Fortunately, this simplifies the computations because you have only to multiply by 0.563 (fig. 9–4). It is not necessary to divide by advance range as you must to determine cross wind.

The correction for range wind then becomes

$$k \times Sw \times Tf \times 0.563 \text{ yards.}$$

But, as with cross wind, k varies with range. Consequently, a value like $K1 - K2/Tf$ is substituted for k in the above formula. This gives

$$\text{range-wind correction} = (K1 - K2/Tf) \times Sw \times Tf \times 0.563.$$

Multiplied out and simplified, you get

$$\text{rage-wind correction} = (K1 \times Sw \times Tf - K2 \times Sw)\ 0.563.$$

This equation can be solved with a multiplier, a Tf cam,

Digitized by Google

and a couple of gear ratios as shown in figure 9–8. *R2* positions the *Tf* cam to produce the *Tf* output, which is multiplied by *K1* in a gear ratio. The output of the gear ratio is $Tf \times K1$, and is multiplied in the multiplier by *Sw*. The multiplier output is $K1 \times Tf \times Sw$.

At the same time, *Sw* is multiplied by *K2* in another gear ratio and subtracted from the multiplier output in DF1. Then the output of DF1 is multiplied by 0.563 in a third gear ratio to complete the computation of range-wind correction. The correction is added to *R2* in DF2, completing the entire process of range correction for wind.

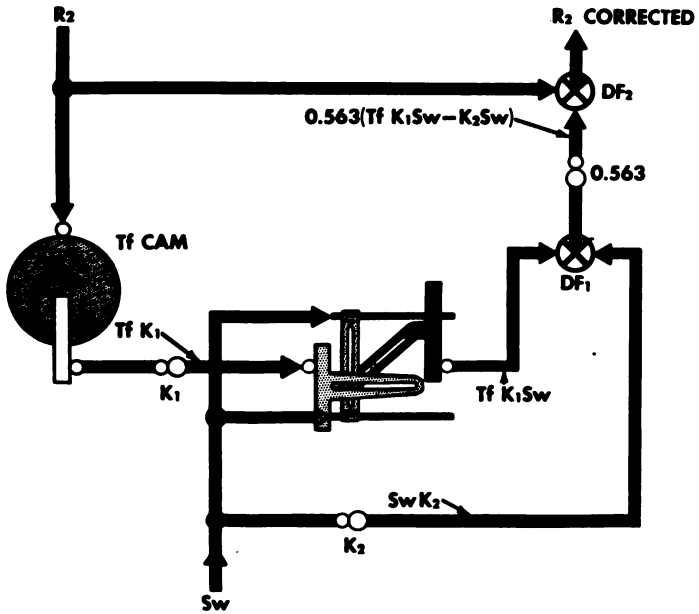


Figure 9–8.—Computing range-wind correction.

It's important that you thoroughly understand these calculations in figure 9–8. Trace out the mechanical arrangement of the parts, and follow the mathematics solved at each step.

Digitized by Google

WIND AT AN ANGLE

Up to now you've learned about corrections for wind blowing directly across and along the LOF. It is seldom, however, that wind will be so accommodating as to limit itself to these directions. Instead, it generally comes from a direction that makes an oblique angle with the LOF.

Before you can study winds at such an angle, it's necessary to define a few angles.

Customarily, you always describe a wind by indicating the direction it is coming FROM. An east wind is blowing FROM the east, toward the west. For this reason the direction of the wind is always measured from north in a clockwise direction to the direction from which the wind is coming.

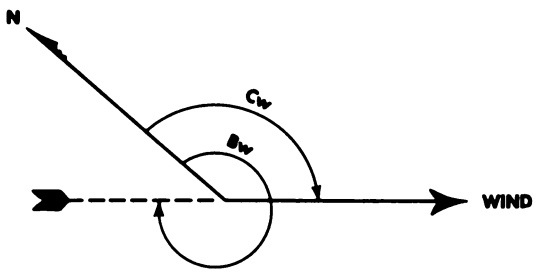


Figure 9–9.—Angles used to compute wind correction.

Figure 9–9 shows two wind angles. The first is *Bw*, TRUE-WIND DIRECTION. This is the value of wind furnished by the aerological party, and is the value you set up on the dials of a rangekeeper.

Bw is not used as it stands in solving the fire control problem, because quantities such as wind are measured to or from the arrowhead end of a vector. So, instead of *Bw*, a quantity known as WIND COURSE (*Cw*) is used. *Cw* is measured from the direction toward which the wind is blowing as indicated. A study of the figure will tell you that

$$Cw = Bw - 180$$

or,

$$Cw = Bw + 180.$$

Digitized by Google

The whole idea of the wind problem is to take a wind of known direction and speed and resolve it into components in and across the LOS. Then you take these components and proceed as you did with range and cross wind.

Notice that you use the LOS rather than the LOF. For true accuracy you should use the LOF, but since *Ds* is comparatively small in surface fire control, the LOS makes a good enough reference. However, for fast-moving air targets, *Ds* is so large that it is necessary to use the LOF.

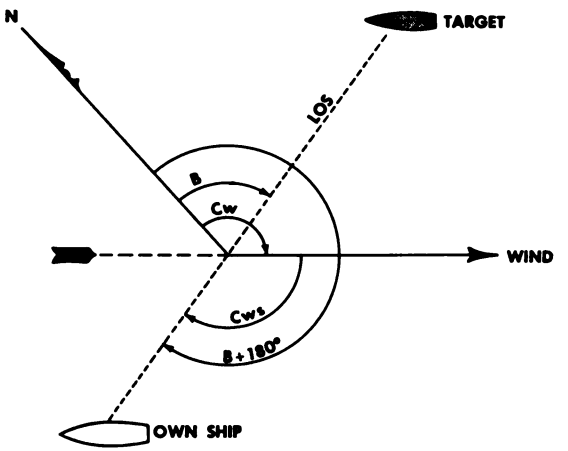


Figure 9–10.—Wind course measured relative to the LOS.

The angle the wind makes with the LOS is called *Cws* (standing for wind course relative to the LOS), shown in figure 9–10. It is measured from the arrowhead of the wind vector clockwise to the LOS. To obtain this angle you must know the true direction of the LOS, so you use true target bearing, *B* (measured from north clockwise to the LOS).

However, there's another hitch. *B* isn't measured directly, but instead, is made up from *Br* and *Co*. *Br* is measured by the director, and *Co* is received automatically from the master-gyro compass: they can also be cranked in manually by handcranks. As shown in figure 9–11, *B* is equal to

$$B = Br + Co.$$

Digitized by Google

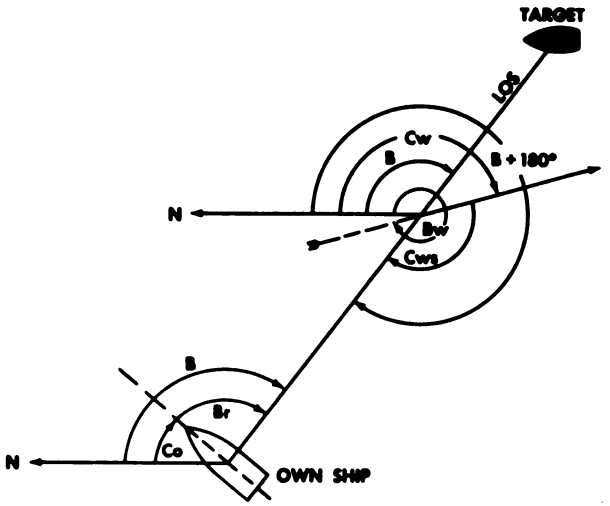


Figure 9–11.—How Cws is obtained.

Now that you have the true direction of the LOS, you're ready to find *Cws*. It is computed from *B* and *Cw* as shown in figure 9–11. A study of the figure will tell you that

$$Cws = (B + 180) - Cw.$$

Cws can be solved in the rangekeeper with a couple of differentials as shown in figure 9–12. *Co* and *Br* are added in

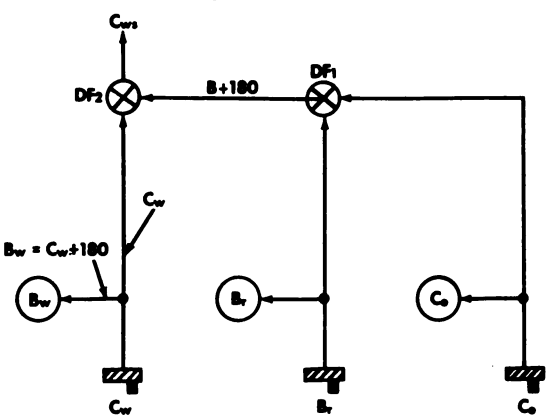


Figure 9–12.—How Cws is computed mechanically.

Digitized by Google

DF1 to give B; and $(B+180)$ and Cw are subtracted in DF2 to give Cws, in degrees. The 180 constant is put in by slipping the shaft connecting DF1 and DF2 by 180°.

RESOLVING THE WIND VECTOR

So far you know these things about the wind vector: first, you know its direction (Cws) with respect to the LOS; second, you know its speed, Sw. That gives you the set-up in figure 9–13. Also, you know that wind has two effects—the effect of pushing the projectile sidewise, and that of shortening or lengthening range. So you resolve the vector into its two right-angle components, Xw and Yw. Xw is the cross-wind component, and Yw is the range-wind component. From your knowledge of trigonometry you know that these components added will have the same effect as the single vector Sw.

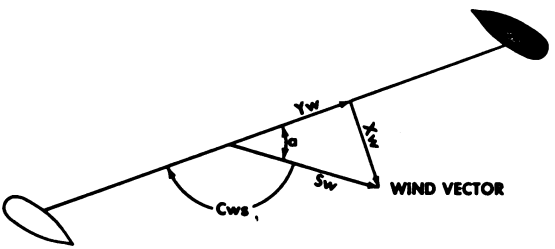


Figure 9–13.—The wind vector.

That leaves only the problem of breaking down Sw into its components with the component solver. To calculate the values of the components, notice that

$$Xw = Sw \times \sin Cws$$
$$Yw = Sw \times \cos Cws.$$

For the case shown in figure 9–13, remember that the trigonometric functions of Cws are the same as those for angle a except for its numerical sign, because a is the supplement of Cws. Angle a equals $180° - Cws$.

Actually, in the wind problem you don't have to worry about the sign of trigonometric functions, because the component solver automatically comes up with the correct sign.

Digitized by Google

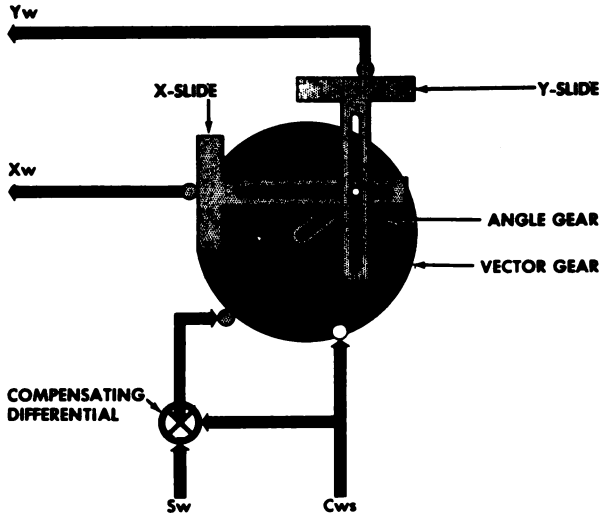


Figure 9–14.—Resolving the wind vector with a component solver.

Figure 9–14 shows how the component solver breaks down *Sw*, *Cws* is the input to the angle gear and *Sw* is the input to the vector gear. Then *Xw* and *Yw* are the slide outputs.

Right here would be a good time for you to brush up on the component solver if you've forgotten how it works. Can you explain to yourself what the compensating differential does? If not. it's time to review component solvers in chapter 4.

SIMPLIFIED MECHANICAL WIND COMPUTER

How would you like to sum this whole chapter up in one diagram? Figure 9–15 does just that. It takes the wind vector, resolves it into the *Xw* and *Yw* components, and solves for cross-wind and range-wind corrections. This set-up is one similar to those used in rangekeepers controlling surface fire.

First, notice the formation of the inputs to the wind component solver. Wind speed *Sw* is inserted by rotating the wind-speed crank until the proper value shows up on the *Sw* dial. *Br* and *Co* are shown as being put in by hand cranks.

Digitized by Google

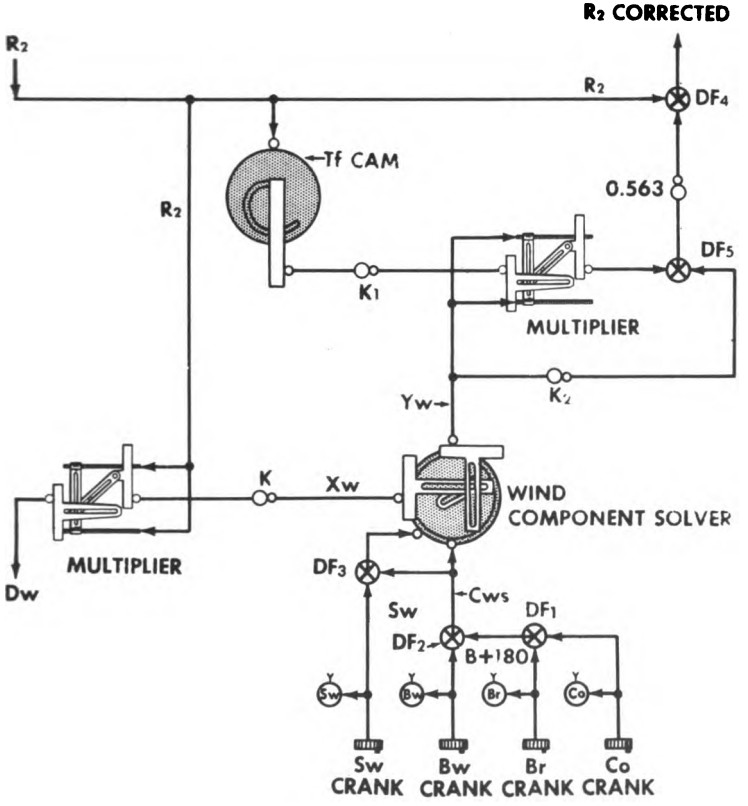


Figure 9–15.—Example of a device to compute wind correction.

You know, of course, that these values come in automatically. Then *Br* and *Co* are combined in DF1 to give *B*.

The wind-direction crank actually puts *Cw* into the hook-up, but the indicating dial is connected up 180° out, so it reads wind bearing, *Bw*.

Cw is combined with *B* in DF2 to give *Cws*. This is the angle input to the wind component solver. *Cws* is constantly changing as the target moves, but with this set-up you need to introduce wind values only once. Then, if correct values of *Br* and *Co* are maintained, the correct value of *Cws* will always show up on the component-solver input.

Digitized by Google

DF3 is the compensating differential which is found in every component solver. You will recall that it prevents the length of the vector from changing when the angle changes.

Deflection correction due to *Xw* is solved exactly the same as shown back in figure 9–7 except that *Xw* is substituted for *Sw*. Range correction due to *Yw* is solved the same as it was back in figure 9–8, except that *Sw* is again substituted for, but this time by *Yw*.

Follow through the computation for range and cross wind in figure 9–15, and review the computations step by step. The range component (*Yw*) of the wind vector (*Sw*) is fed into the upper multiplier. The other input to the multiplier is *Tf*, which is obtained from a cam and multiplied by the constant *K1* in a gear ratio before positioning the slide input. Then *Yw* is multiplied (by gearing) by another constant (*K2*) and the result is subtracted from the output of the multiplier in DF5. The result is the correction for advance range to compensate for range wind, and is combined with advance range at DF4.

Mils deflection due to wind is obtained by the approximate formula, $K \times Xw \times R2$. *R2* and the *Xw* component of the wind vector are the inputs to a multiplier. The output is deflection due to wind, *Dw*.

This completes the study on wind corrections. It has told you about wind, but just as important, it has shown you how computing units like multipliers, differentials, and component solvers work together.

Digitized by Google

QUIZ

From the following select the answer (*a*, *b*, *c*, or *d*) which BEST completes the statement or answers the question.

1. When winds are weighted and plotted for different levels, the result is

   (*a*) average air density.
   (*b*) ballistic wind.
   (*c*) wind speed.
   (*d*) wind direction.

2. Which of the following winds is never considered when solving the fire control problem?

   (*a*) Vertical wind.
   (*b*) Ballistic wind.
   (*c*) Range wind.
   (*d*) Cross wind.

3. In order to convert linear deflection due to cross wind to mils, it is necessary to divide by

   (*a*) 0.563.
   (*b*) 3.43.
   (*c*) Advance range.
   (*d*) The reciprocal of R_2.

4. Which of the following formulae will give the approximate correction in yards for range wind?

   (*a*) $Sw \times Tf \times \frac{Tf}{R2} \times K$.
   (*b*) $Sw \times Tf \times K$.
   (*c*) $\frac{Sw \times Tf \times K}{R2}$.
   (*d*) $Sw \times Tf \times K \times 0.563$.

5. The angle the wind makes with the line of sight is called

   (*a*) *Bw*.
   (*b*) *Cws*.
   (*c*) *Bws*.
   (*d*) *Cw*.

6. Wind course relative to the LOS is computed by which of the following formulas?

   (*a*) $Bw - 180$.
   (*b*) $(Cw + 180) - B$.
   (*c*) $(B + 180) - Cw$.
   (*d*) $Br + Co$.

Digitized by Google

7. The wind vector is resolved into components in and across the LOS by means of a
   (*a*) Component solver.
   (*b*) Vector solver.
   (*c*) Component integrator.
   (*d*) Resolver.

8. Which of the following symbols indicates the wind deflection components?
   (*a*) *Yo*.
   (*b*) *Yw*.
   (*c*) *Sw*.
   (*d*) *Xw*.

9. The wind deflection and range components in and across the LOS are computed by multiplying *Sw* by the sine and cosine of
   (*a*) *Bw*.
   (*b*) *Cws*.
   (*c*) *Bws*.
   (*d*) *Cw*.

10. A cross wind deflects the projectile the most at the
   (*a*) middle of the trajectory.
   (*b*) end of the trajectory.
   (*c*) beginning of the trajectory.
   (*d*) highest point of the trajectory.

11. One mil is equal to the angle whose tangent is
   (*a*) 1/10.
   (*b*) 1/100.
   (*c*) 1/1000
   (*d*) 1/10,000.

12. If 2,027 yards per hour is equal to 1 knot, the constant for converting knots to yards per second is
   (*a*) 0.356.
   (*b*) 0.365.
   (*c*) 0.563.
   (*d*) 0.653.

Digitized by Google

CHAPTER 10

THE RELATIVE MOTION PROBLEM

FIRE BETWEEN MOVING SHIPS

The gun position must now be corrected for own ship and target motion as well as for the effect of wind, gravity and air resistance. You have studied all but own ship and target motion thus far, and back in the chapters on computing units you learned how to resolve and add vectors, so this chapter is just another step which shouldn't alter your pace in the least if you are thoroughly familiar with the foregoing material.

Let's size up the problem for a moment by starting with the data received from the director. The director, as you know, measures the range and bearing of the target PRESENT POSITION, the actual spot where the target is at any time. But what the rangekeeper does is to take this information, along with estimated target course and speed, and predict where the target will be after Tf has elapsed. That is, the rangekeeper must compute the FUTURE TARGET POSITION relative to own ship, and the line of fire (LOF) to the future target position. In surface rangekeepers the LOF is determined by computing the gun elevation and train orders ($E'g$ and $B'gr$).

The rangekeeper starts by solving the problem for own ship and target motion with a set of component solvers. But before you can understand this component-solver action, you'll have to know a little about the mathematical solution.

Digitized by Google

Own Ship Motion

Think for a moment about the effect of own ship motion on the projectile. When the ship is stationary with no wind present, the projectile has only one velocity when fired—its initial velocity, *I.V.* But when the ship is moving, the projectile has two velocities: the *I.V.* and own ship speed, *So.* Own ship motion will be transferred to the projectile at the instant it's fired, and will act on it throughout its flight. Obviously, the point of aim of the gun must be changed in order to hit the target. And, of course, these changes will appear in sight angle, *Vs* and sight deflections, *Ds.*

For example, if own ship is moving toward the target the gun must be depressed in order to keep from over-shooting. That is, *Vs* must be DECREASED. Or, if own ship is moving leftward relative to the target, the gun must be trained right to keep from landing the projectile left—*Ds* must contain a RIGHT correction.

Own ship motion is always represented by a vector whose magnitude is *So* (own ship speed), and whose direction is *Br* (relative target bearing) measured from the ship's centerline clockwise to the line of sight, LOS, as shown in figure 10–1. You will recall that *So* (own ship speed) is received from the pitometer log, and that *Br* (relative target bearing) is measured by the director.

Bear in mind that relative target bearing can be measured directly by the director only when the deck is level; a deck tilt correction must be added to director train to produce *Br* when the deck is tilted. Both *So* and *Br* are received by synchro transmission.

A look at the figure will show that *So* has two effects: that of shortening or lengthening range, and that of deflecting the projectile left or right. To find the effect of own ship movement on the range and on the deflection of the projectile, you have to break own ship speed *So* into components along and across the LOS as you did with wind speed. These components are *Xo* and *Yo.* The DEFLECTION COMPONENT *Xo* is calculated by multiplying *So* by sin *Br*, and

Digitized by Google

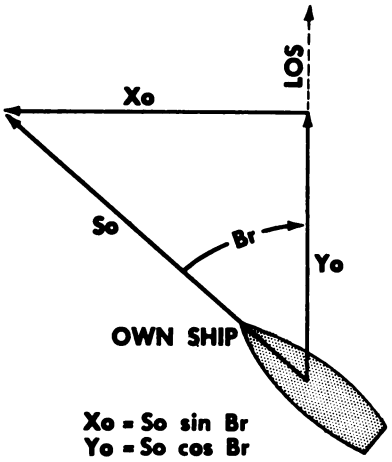


Figure 10–1.—Components of own ship movement.

the RANGE COMPONENT Yo is found by multiplying So by cos Br.

These components can be obtained mechanically from a component solver by setting Br in the angle gear, and So in the vector gear. You learned that back in the chapter on component solvers.

If you multiply Yo by Tf, and affix the correct sign, you have the correction for range due to own ship movement. Of course, this neglects air resistance; as the shell moves at speed Yo (in addition to $I.V.$), it will have to push through the air and will be slowed down. So the total error will be less than $Tf \times Yo$. By the same reasoning, the value of the linear deflection would be $Xo \times Tf$ neglecting air resistance.

Target Motion

Target motion can be treated in exactly the same way as own ship motion. The target vector has a magnitude of target speed (S or Sh) and a direction measured by the target angle, A. Target angle is measured clockwise from the bow of the target to the LOS as indicated in figure 10–2.

Digitized by Google

The target-speed vector is broken down into components along and across the LOS the same as the own ship speed vector. These components are the target deflection component (Xt) and the target range component (Yt).

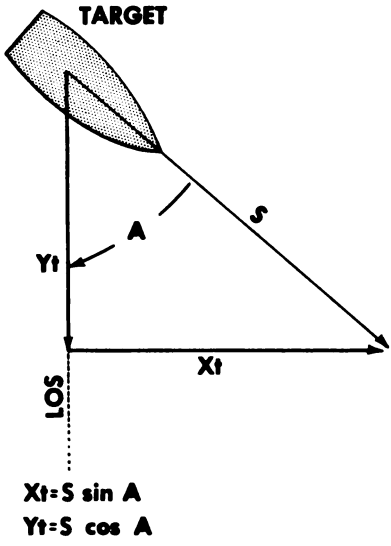


Figure 10–2.—Components of target motion.

As shown in figure 10–2, Yt is obtained by multiplying S by cos A, and Xt by multiplying S by sin A. You can solve the range and deflection errors created by target motion by multiplying each by Tf. Of course the corrections would carry opposite signs to those of the errors.

Don't forget that the X components must be converted to mils before they can become a correction to Ds. You'll remember this from the wind problem.

Solving Own Ship and Target Motion

Now you can lay out the own ship and target motion vectors on the same diagram showing all their references and angles as demonstrated in figure 10–3. This figure shows the relationship of the own ship and target vectors, along

Digitized by Google

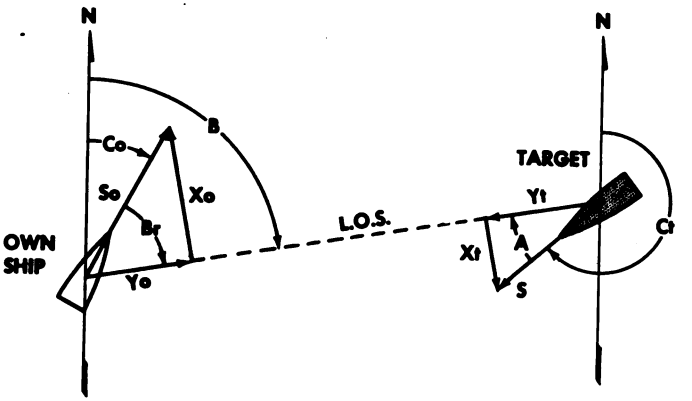


Figure 10–3.—Navigation plot of own ship and target motion.

with all angles, plotted with respect to true north in a navigation plot.

Target angle A can be estimated directly by the control officer in the director and transmitted to the plotting room via telephone. The estimated angle A is then cranked in at

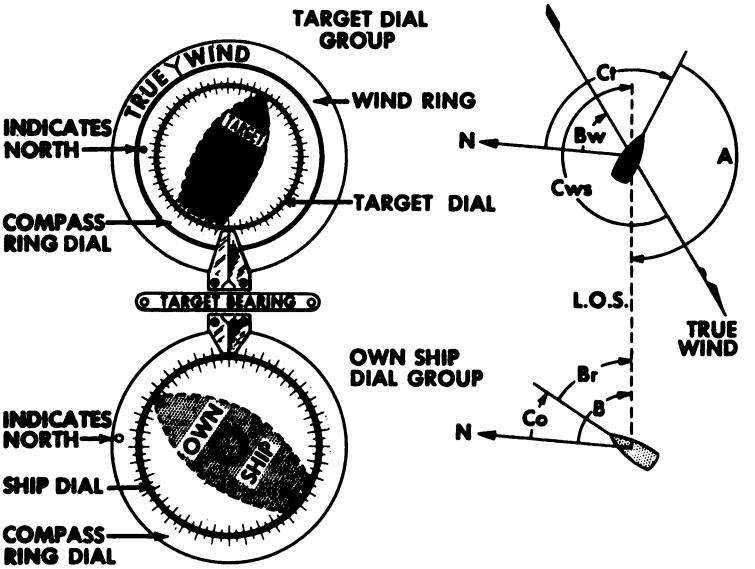


Figure 10–4.—Own ship and target dial groups.

Digitized by Google

the rangekeeper by the operator as noted on the target dial group shown in the upper half of figure 10–4.

Target course (*Ct*) may be transmitted from CIC. Like *A* it is cranked in while observing the target dial group. However, *Ct* is measured from north, and is read at the target ship's head on the CENTER RING DIAL (compass ring dial in figure 10–4); whereas target angle is read on the INNER DIAL (target dial) which is calibrated in degrees measured clockwise from the bow of the target ship to the LOS. Notice that the LOS is always fixed by an imaginary line formed by the lines engraved in the two indexes at the target and own ship dial groups. Regardless of whether you crank in *A* or *Ct* at the rangekeeper, you'll always use the *Ct* handcrank. But, of course, it makes no difference as long as you turn the crank until the dials are in the proper position.

At the OWN SHIP DIAL GROUP you can read own ship course (*Co*), true target bearing (*B*) and relative target bearing (*Br*). Own ship course is read on the INNER DIAL with respect to the north mark on the compass-ring dial. *B* is measured from north clockwise to the LOS, and is read on the RING DIAL at the LOS index marks. And *Br* is read on the INNER DIAL at the LOS index as measured from the bow of own ship.

You can get a firm picture in mind of how these angles are set up on the dials by studying the navigation plot of the angles on the right side of figure 10–4. Notice that own ship and target of the navigation plot and in the dial groups are lying in exactly the same position.

One other thing is illustrated in figure 10–4. Notice that *Bw* is cranked in by watching the angle the outer ring dial makes with north as read on the center ring dial.

Be sure you understand that when *A* is correct you also can read the correct value of *Ct* from the dials, or vice versa. This is because *A* is solved from *B* (which is equal to *Co*+ *Br*) and *Ct* in the formula:

$$A = (B + 180) - Ct.$$

The business of calculating *A* is a little tricky, but quite sim-

Digitized by Google

ple once you catch on—in fact, you do the same thing you did when you solved for *Cws* from *B* and *Cw* in the wind problem. Look at figure 10–4 and notice that *B* is measured from north clockwise to the LOS at own ship, NOT from north clockwise to the LOS at the target. This is why you must add 180° to *B* to make the formula work out right.

To summarize the own ship and target-motion calculations, study figure 10–5. It should be familiar because you covered these very same problems back in the chapter on component solvers. Here, the own ship and target vectors along and across the LOS are superimposed on the own ship and target component solvers.

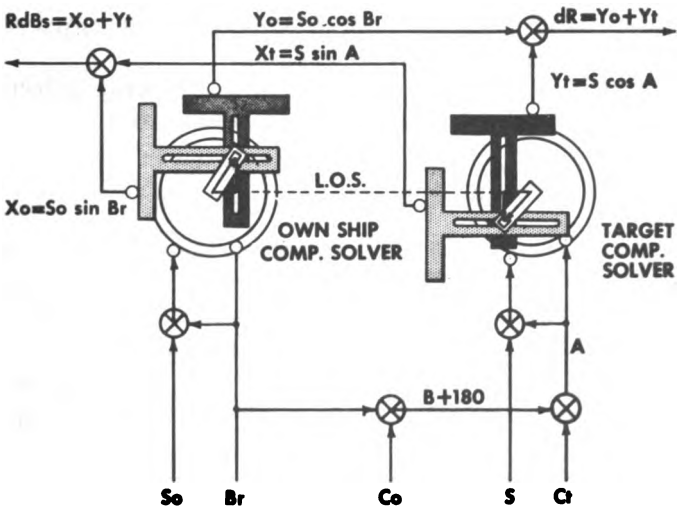


Figure 10–5.—Solving own ship and target motion components.

The angle gear of the target component solver is positioned by angle *A* which is made up from *Br*, *Co*, and *Ct* by the differentials shown in the figure. Then *S* and *A* position the vector gear and the compensating differential to give the vector input. The outputs at the component-solver racks are *Xt* and *Yt*.

The own ship components are solved exactly the same way,

Digitized by Google

except that *Br* and *So* position the inputs to the own ship component solver, and the outputs are *Xo* and *Yo* as indicated.

Linear rates

The next step in solving the surface fire control problem is adding up the components you have just computed. When *Yo* and *Yt* are ADDED you get LINEAR RANGE RATE *dR*, which is a particularly useful quantity used in rangekeeper calculations because it tells the total speed with which range is changing.

Likewise, when *Xo* and *Xt* are added you get the LINEAR DEFLECTION RATE *RdBs*, which is measured in yards at the target. After being converted to mils it tells the speed with which the deflection angle is changing.

Remember that the linear range rate and linear deflection rate are expressed by the following additions:

$$dR = Yo + Yt \text{ yards/second}$$
$$RdBs = Xo + Xt \text{ yards/second.}$$

To sum them up in one small statement, these quantities represent the time rate of change of range and linear deflection.

The plus signs in the above expressions are not always correct as they refer only to the general case. These components can be either positive or negative in accordance with the arbitrary rule that a range component of own ship or

COMPONENT	ANGLE Br OR A	SIGN OF ERROR	SHOT FALLS (ERROR;	CORRECTED FOR BY	SIGN OF CORRECTION
Y RANGE	0-90 270-0	PLUS	OVER	DEPRESSING	MINUS
	90-180 180-270	MINUS	SHORT	ELEVATING	PLUS
X DEFLECTION	0-180	MINUS	LEFT	TRAIN RIGHT	PLUS
	180-360	PLUS	RIGHT	TRAIN LEFT	MINUS

Figure 10–6.—Summary of range and deflection components.

Digitized by Google

target motion (the correction) is considered PLUS if it tends to INCREASE range, and MINUS if it tends to DECREASE range.

Similarly, the deflection component of own ship or target motion (the correction) is considered PLUS if it tends to INCREASE the relative target bearing, or MINUS if it tends to DECREASE the relative target bearing. You can tie this rule together in the chart of figure 10–6.

RANGE PREDICTION

Since own ship and target are continually changing positions while the projectile is in the air, it is necessary to predict the future target position from changes in range rate dR and changes in linear deflection rate $RdBs$. These computations are in addition to the regular trajectory corrections.

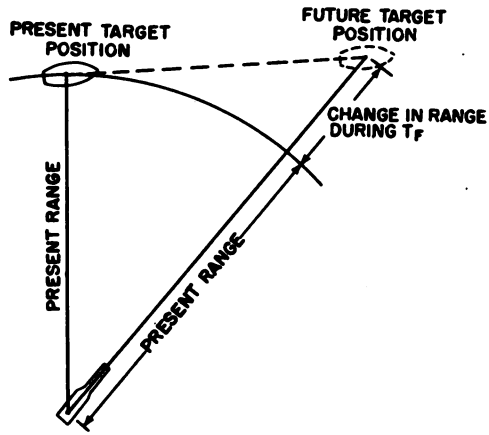


Figure 10–7.—Range prediction.

Figure 10–7 shows what happens to range during time Tf. The range changes, which means that you must determine exactly how much it will change and then add the total change to present range. This addition gives advance range, $R2$.

Once $R2$ is determined, it is easy to compute the sight angle, Vs. Back when you studied the range tables, you found

Digitized by Google

that for every given range there's a corresponding value of *Vs* (fig. 10–8). You also found that *Vs* will increase or decrease with range, but not directly. So the logical thing to do would be to compute *Vs* from a *Vs* cam which is positioned by *R2*. (This is exactly what you did for the computation of drift—remember?) Almost all of the surface rangekeepers compute *Vs* with a cam; in any event, a cam cut to some function of *Vs* and *R2* will be used.

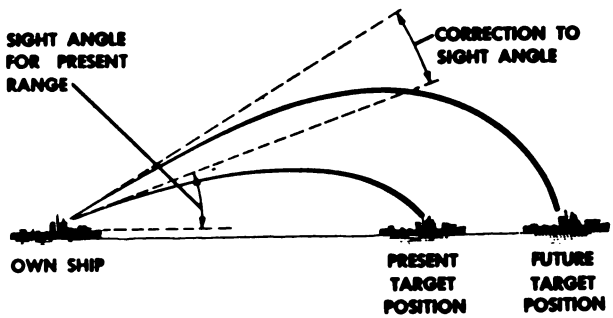


Figure 10–8.—Sight angle for a moving target.

Now in this seemingly roundabout way of getting *Vs*, the big problem becomes the calculation of the total change in range—that is, to determine range prediction due to own ship and target motion, *Rt*. It can be computed in a number of ways, but regardless of how it's done, it'll always seem a little difficult.

You will recall that *dR* tells the speed with which range is changing, so at first thought it might seem logical to multiply *dR* by *Tf* to give total change in range. Your answer would be correct only for slow-moving targets, because the value of *Tf* was taken to present range—the only available value of range you have.

To be correct, *Rt* must represent the amount the range changes (due to own ship and target motion) during the time (*Tf*) it takes the projectile to get to the target. With this in mind, it should be obvious that you can't compute *Rt* from the *Tf* based on the range to present target position.

Digitized by Google

Instead, a *Tf* based on a certain range nearly equal to *R2* should be used; however, for all practical purposes, a *Tf* based on *R2* is used.

But here's the catch—how in the world can you calculate *Tf* based on *R2*, when you need *Tf* to calculate *Rt* to get *R2*? Sure, it sounds like a vicious circle, and, strange as it may seem, it actually is!

You can get the correct value of *Tf* by a regenerative process which is done by feeding the output back into the input of a mechanical range-prediction computer. This is really the same as putting in a series of substitutions, which is carried on indefinitely in the machine until the answer—*Rt* and, in turn, *Tf*—is correct.

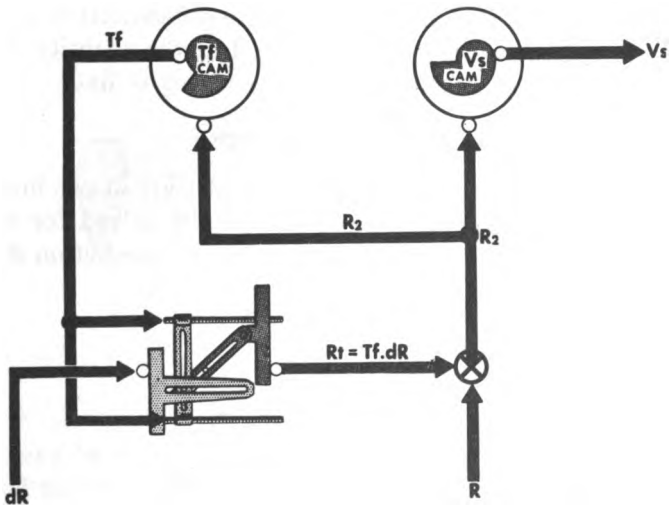


Figure 10–9.—Computing Vs with a simple ballistic computer.

An example will probably give you the idea better:

(*1*) Find *Tf* to present range.

(*2*) Multiply quantity (1) by *dR* to get the first approximation of *Rt*.

(*3*) Add quantity (2) to present range to get the first approximation of *R2*.

Digitized by Google

(*4*) Find *Tf* corresponding to the first approximation of *R2*, (3).

(*5*) Multiply quantity (4) by *dR* to get the second approximation of *Rt*.

(*6*) Add quantity (5) to present range to get the second approximation of *R2*.

This could be continued indefinitely, although two substitutions would be accurate enough.

Such a problem is worked by the machine shown in figure 10–9. The *Tf* cam and multiplier solve the equation for range prediction due to own ship and target motion:

$$\text{range prediction} = (Yo + Yt)\ Tf$$
$$\text{or, } Rt = dR \times Tf$$

which is added to present range *R* in the differential to give *R2*. Then *R2* drives the *Vs* cam to produce the quantity *Vs*, which you have spent such a long time trying to find.

DEFLECTION PREDICTION

In solving for range prediction you really killed two birds with one stone, because in doing so, you also solved for the *Tf*. And since *Tf* is used to solve deflection prediction due

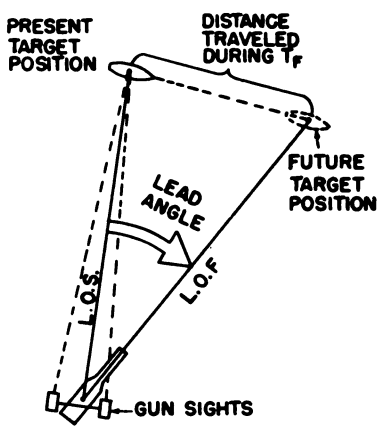


Figure 10–10.—Sight deflection for lead.

Digitized by Google

to own ship and target motion, Dt, half of the deflection problem is already worked out.

But before we get into the details of solving deflection prediction, let's first review the problem and see what deflection actually is. In the most simple case shown in figure 10–10, sight deflection Ds is the angle the gun must be offset from the LOS to allow for own ship and target motion during Tf. In short, you have to PREDICT how much to LEAD the target so that the shell and target will meet at a point at some future time.

Of course, you also have to correct Ds for things such as drift and wind. Therefore Ds includes all the corrections shown in figure 10–11 so

$$Ds = Dt + Df + Dw$$

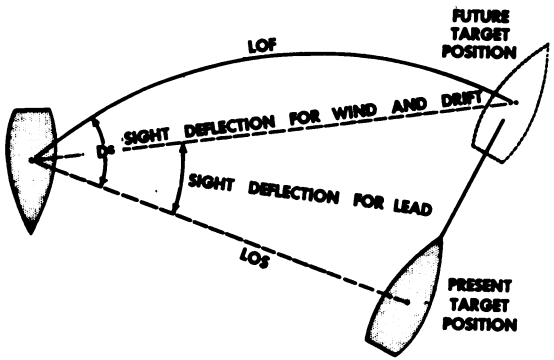


Figure 10–11.—Sight deflection Ds.

where Dt is the deflection necessary to correct for own ship and target motion, Df is the correction for drift, and Dw is the correction for wind.

Now let's calculate Dt. The first step is to multiply $RdBs$ (linear deflection rate in yards/second) by Tf as shown in figure 10–12, which gives linear deflection prediction at the target in yards. Then to convert this value to mils just divide by $R2$ in thousands of yards. Therefore, Dt is equal to:

$$Dt = \frac{RdBs \times Tf}{R2} \text{mils.}$$

Digitized by Google

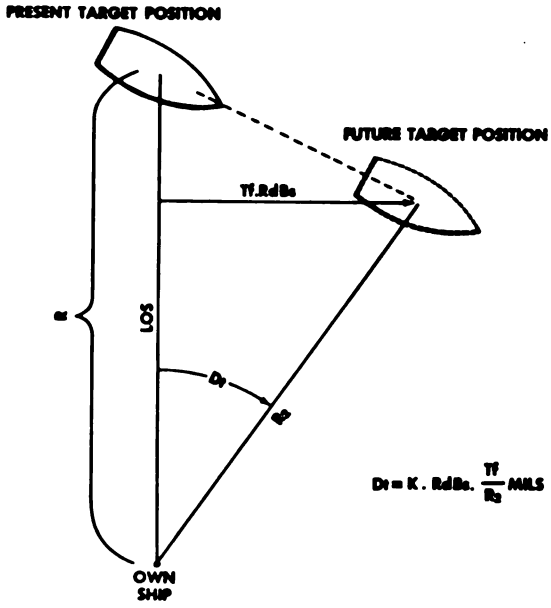


Figure 10–12.—Deflection prediction for own ship and target motion.

In some cases it is necessary to have Dt in minutes rather than mils. This is a simple operation because all you have to do is to multiply by 3.43, since 1 mil equals approximately 3.43 minutes. This can be handled by a gear ratio.

The simpliest way of solving Dt in a rangekeeper is shown in figure 10–13A. This method involves only the use of a multiplier and a gear ratio to convert the product to minutes. However, a more accurate method, the one you'll generally encounter, uses a differential in addition to the multiplier as in figure 10–13B. This latter method is more accurate because it utilizes the entire range of the multiplier.

You will recall that multipliers are built so that both inputs can go to zero. This is done so that, when doing a multiplication in which one of the terms never reaches zero, there will be an unused portion of the multiplier. For a given range of inputs, the greater the amount of the multiplier which can be used, the greater the accuracy. For this reason

Digitized by Google

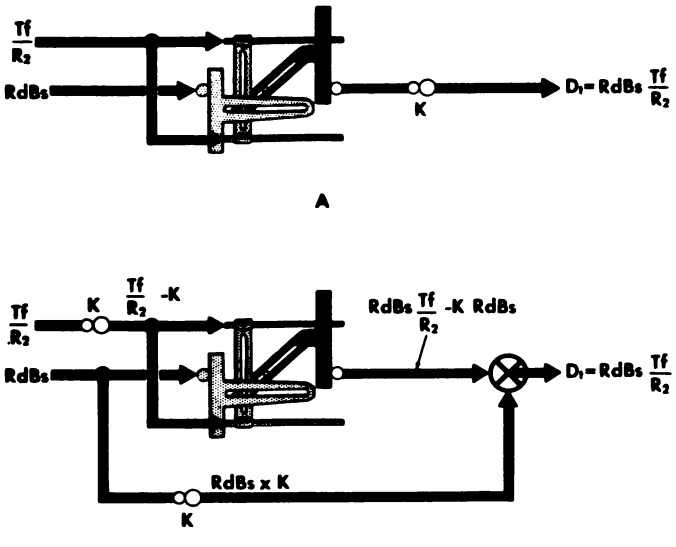


Figure 10–13.—Computing *Dt*.

attempts are often made to use full range of both slides from zero to maximum. And that is exactly what the arrangement in figure 10–13B is designed to do.

The expression $Tf/R2$ never reaches zero because the minimum range input never reaches zero. But by replacing the input $Tf/R2$ with an input $Tf/R2-K$, where K equals the minimum value of $Tf/R2$, the $Tf/R2-K$ input will go to zero.

Inspection of the schematic of figure 10–13B, shows how the resulting unwanted $K \times RdBs$ in the product is removed in the differential by subtracting an equal quantity made from multiplying $RdBs$ by K in a gear ratio. This actually increases utilization of the $Tf/R2$ slide of the multiplier by about 30 percent.

No doubt you are getting "K happy" by this time, but unless you stop once in a while to figure out what these various K values mean, a basic understanding of rangekeepers is impossible. However, we've been keeping as many of them out

Digitized by Google

of the picture as possible and will continue to do so. You can learn a great deal from figure 10–13B, because this way of obtaining greater accuracy is used many times to compute other quantities.

RANGE EFFECT OF DEFLECTION AND I.V. CORRECTION

The simple formula you used to calculate *R2* (and *Vs*) is not always accurate enough for mechanical rangekeepers and computers used in main battery and antiaircraft plotting rooms, because deflection prediction introduces a RANGE ERROR (see fig. 10–14). For small deflection angles this error is

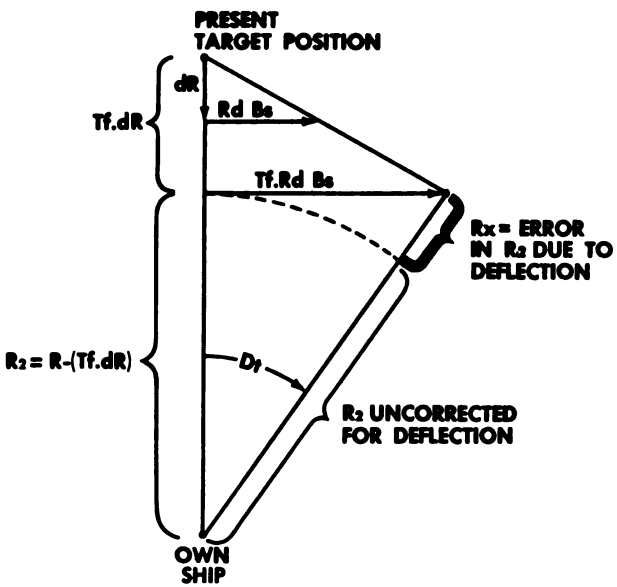


Figure 10–14.—Error in R2 due to deflection.

negligible, but when targets move fast the deflection is increased and so the error in *R2* grows larger. A study of the diagram will reveal that where no deflection is present the error is zero.

Digitized by Google

The correction for range effect of deflection is called the range prediction due to deflection, and is represented by *Rx*. Rangekeepers make up *Rx* in a number of different ways. Even so, *Rx* will always be based on the fact that it is nearly proportional to *R2 times* $(Dt)^2$, where *Dt* is mils deflection due to own ship and target movement.

Some rangekeepers go a little further by taking a new value (*Dtw*) based on the deflection prediction due to wind as well as for own ship and target motion ($Dtw = Dt + Dw$), exclusive of drift, and substitute this value for *Dt*. Then you can more accurately write:

$$Rx = R2 \times (Dtw)^2.$$

But, like most problems in fire control, this problem grows a bit more complicated because, in actual practice, the rangekeeper also solves the range prediction to compensate for changes from initial velocity (*Rm*), in the same mechanism. Of course, this is more practical from the construction standpoint because it eliminates an extra multiplier which would otherwise be necessary if *Rx* and *Rm* were solved separately. (Refer to the appendix for definitions of symbols.)

A computer that determines range prediction due to *I.V.* changes, deflection due to wind, and deflection due to own ship and target motion is shown in figure 10–15. It may

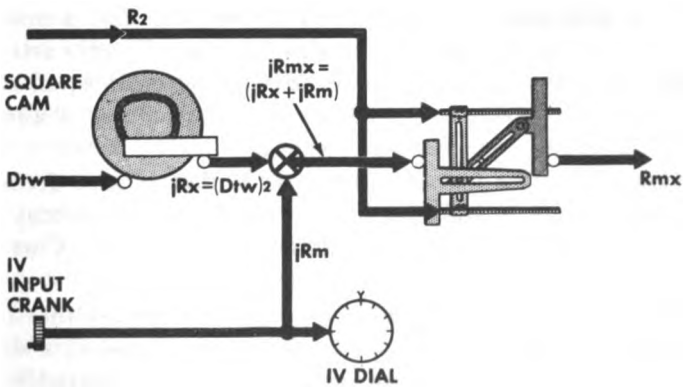


Figure 10–15.—Range prediction due to *I.V.* changes, wind and deflection.

Digitized by Google

appear to be a little complicated, but it is really quite simple compared with some computing mechanisms you've already covered.

Take one thing at a time, starting with *Dtw*. First, *Dtw* is squared according to the basic formula, $Rx = R2\ (Dtw)^2$, in a cam to give partial range prediction due to cross wind and own ship and target motion, *jRx*, which is equal to $(Dtw)^2$. Then *jRx* is added to partial range prediction due to *I.V.* change, *jRm*, and the sum ($jRmx = jRx + jRm$) is fed to the multiplier.

NOTE: The "*j*" preceding the symbols indicates partial correction.

Finally *jRmx* is multiplied by *R2* in the multiplier to give *Rmx*. In practice, *R2* plus some constant is used as the screw input to the multiplier, which is just another trick to get better results.

The *I.V.* dial is calibrated so that, when you apply a correction in so many feet/second, the proper correction (*jRm*) is applied to the multiplier input. And when *jRm* (along with *jRx*) is multiplied by *R2*, the result produces the proper range correction due to *I.V.* change.

WIND CAUSED BY OWN SHIP MOTION

As a ship steams through still air you can feel a breeze which has the same effect as a wind blowing directly astern. It is called HEAD WIND. The head wind speed is equal and opposite to own ship speed. If own ship is making 10 knots, then the head wind speed is 10 knots.

Consider, for a moment, a projectile that is fired from a moving ship. In addition to all other forces which may be acting upon it, head wind will resist the projectile. Corrections for this head wind must be made to get hits.

Now, in addition, consider what happens when the ship is sailing along with an actual wind present, and this wind makes an angle with the ship's course as shown in figure 10–16. Two wind forces are now acting on the projectile. But here

Digitized by Google

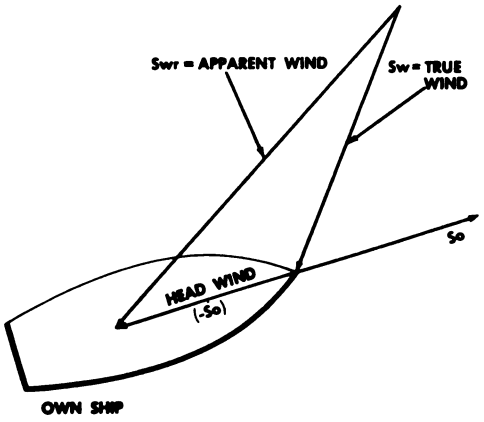


Figure 10–16.—Apparent wind.

again you can think of these two winds as one resultant wind called APPARENT WIND, *Swr*. The figure shows how true wind and head wind are combined to give *Swr*.

In computing the effect of apparent wind on the trajectory of the shell, you could proceed as usual except that you would use the apparent wind speed *Swr* instead of true wind *Sw*. And, of course, you would use apparent wind direction *Bwr* instead of true wind direction *Bw*.

There's a decided disadvantage in using apparent wind angle and speed as rangekeeper inputs, because every time own ship changes course or speed, the value and direction of the velocity vector of apparent wind also changes. You can see why this is true in figure 10–16; assume that own ship changes course with respect to true wind and figure it out for yourself. Most rangekeepers take *Sw* and *Bw* as inputs, because they never have to be changed unless true wind changes. The *Sw* vector is then resolved into *Xw* and *Yw* components along and across the LOS, and added to the own ship components.

This may look like a roundabout way of calculating corrections for apparent wind, but the nice thing about it is that this method automatically takes care of apparent wind changes due to changes in own ship course and speed. Thus,

Digitized by Google

when you add the true wind and own ship components, you get the apparent wind components ALONG and ACROSS the line of sight. Mathematically you can write:

$Xwr = Xw + Xo$ = component of apparent wind velocity ACROSS LOS.

$Ywr = Yw + Yo$ = component of apparent wind velocity ALONG LOS.

As you learned in the wind chapter, Xwr corrects sight deflection Ds, and Ywr corrects sight angle Vs by correcting advance range $R2$. At this point you should get an idea of how these wind quantities are treated in an actual machine. Let's start by studying how Dw is made up from Xwr as shown in figure 10–17.

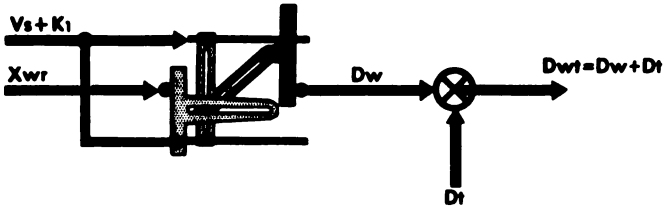


Figure 10–17.—Computing deflection prediction due to wind and own ship target motion.

Way back in figure 9–7 you'll see that Dw was made from $R2 \times K$ Sw (where Sw was assumed to be cross-wind velocity). Well, you can solve for apparent wind in the same formula by substituting Xwr for Sw.

You will also recall that K varies to compensate for the slowing down of the projectile at the end of its trajectory. Thus K varies in the same way as the Tf or Vs functions of $R2$—it increases faster than range. Consequently, instead of being computed from a cam, the value of K is computed from other quantities (usually Vs) already present in the machine.

Some machines compute Dw by multiplying Xwr by $R2 \times K$, as you did in the wind chapter. But other machines, like the one shown in figure 10–17, make up a more accurate

Digitized by Google

value of Dw by multiplying Xwr by $Vs+K$. It should be apparent that $Vs+K$ increases faster and faster at longer ranges, because that is the way Vs varies. If you can't remember how the wind correction varies with range, go back to the wind chapter and review the cross-wind section.

Dw is then added to Dt in a differential to make up deflection prediction due to wind and own ship and target motion, Dtw (fig. 10–17).

Next, see how Ywr is treated. Range prediction due to wind (Rw) is solved in the SAME MULTIPLIER that computes Rt, which of course saves a multiplier. This multiplier is called the RANGE PREDICTOR. Its output is range prediction due to own ship and target motion and wind, Rtw, which is equal to Rt plus Rw; however, neither Rt nor Rw appear SEPARATELY in a rangekeeper, because the multiplier computes them simultaneously.

From the wind chapter (see fig. 9–8) you will recall that

$$Rw=Tf\times K\times Ywr-K1\times Ywr,$$

where Ywr is substituted for Sw (which was assumed to be range-wind). Also, you will recall from figure 10–9 in this chapter that

$$Rt=Tf\times dR.$$

Now, since Rtw is equal to Rt plus Rw, you can write

$$Rtw=Rt+Rw$$

or, by substituting the above values for Rt and Rw you get

$$Rtw=Tf\times dR+(Tf\times K\times Ywr-K1\times Ywr).$$

Also, by removing the parentheses and rearranging:

$$Rtw=Tf\times dR-Tf\times K\times Ywr+K1\times Ywr$$

or,

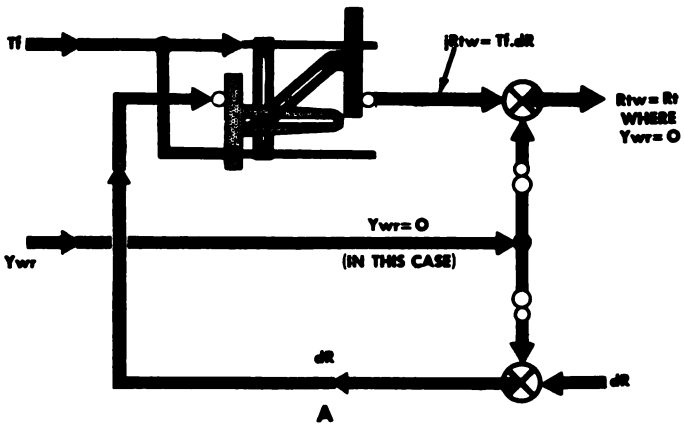
$$Rtw=Tf\ (dR-K\times Ywr)+K1\times Ywr$$

which is the formula the multiplier solves with the assistance of two differentials, and two gear ratios to take care of the

Digitized by Google

constants. In order to keep from repeating the long term $Tf\ (dR-K\times Ywr)$ over and over again on drawings and prints, it has been given the symbol which is called partial range prediction for wind and own ship and target motion, $jRtw$. Then you have

$$Rtw=jRtw+K1\times Ywr.$$



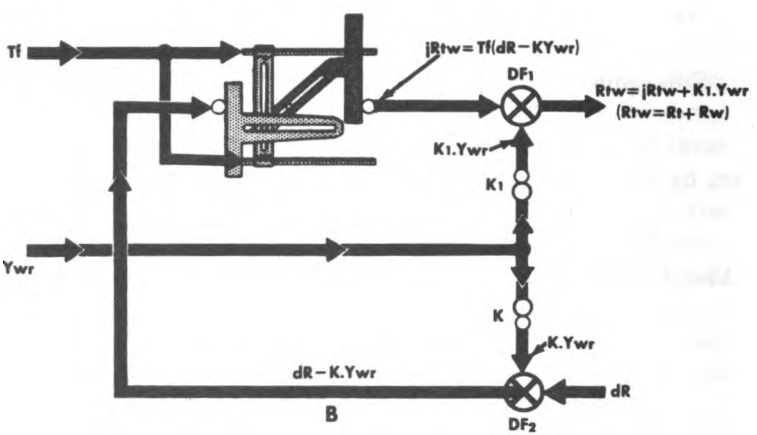


Figure 10–18.—Solving range prediction due to wind and own ship and target motion.

Digitized by Google

Figure 10–18 shows how this formula is solved. To see how the setup works, first assume that *Ywr* is zero (no wind correction present), as shown in figure 10–18A. With *Ywr* at zero the multiplier simply multiplies *Tf* by *dR* to give range prediction due to own ship and target motion *Rt*, which in this case is equal to *Rtw*.

But with apparent wind present as shown in figure 10–18B, the side gears of DF1 and DF2 are offset by *Ywr* (which is modified by the two constants. (Then $K \times Ywr$ is subtracted from *dR* in DF2 to produce $dR - K \times Ywr$, which is multiplied in the multiplier by *Tf* to give *jRtw*. Finally $K1 \times Ywr$ is added to *jRtw* in DF1 to give *Rtw*. You should remember from the wind chapter that the two constants modify wind speed to give the velocity actually imparted on the shell by wind. When this velocity is multiplied by *Tf*, you get the distance in yards that the shell has been moved.

COMPUTING SIGHT ANGLE AND SIGHT DEFLECTION

Now you are ready to wind up this business of own ship and target motion, wind, *I.V.* correction, range and deflection prediction, and make up sight angle (*Vs*) and sight deflection (*Ds*) including ALL their corrections. The best way to learn about *Ds* and *Vs* is to put all the foregoing diagrams together and study them as a whole. Let's take *Ds* first.

The *Ds* computer in figure 10–19 is really just a review of figures 10–13 and 10–17. As you learned earlier, *Ds* is equal to the SUM of *Dt*, *Dw*, and *Df*. Each of these three quantities is computed separately. *Dt* is computed in the TARGET DEFLECTION PREDICTOR multiplier, and *Dw* is solved in the WIND-DEFLECTION multiplier. But *Df* is made up a little different than anything you have computed so far.

If you stop to think back it should be apparent that both *Vs* and *Df* increase with range, but they increase faster and faster as range increases. Thus, you can say that both *Vs* and *Df* vary as functions of *R2*. Since both are functions of advance range, it follows that *Df* is equal to some function of *Vs* which can be expressed mathematically as

Digitized by Google

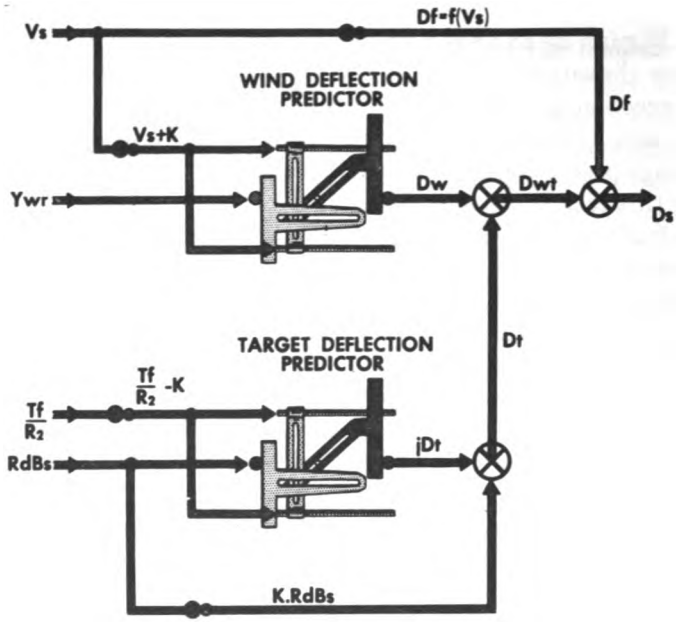


Figure 10–19.—Solving for sight deflection *Ds*.

$Df = f(Vs)$. (See fig. 10–19.) This formula has a very general meaning; however, it shows that there is a relationship between Df and Vs. And that's all you need to know here, because proper shafting and gearing to take care of constants, do the rest. One machine manufactures Df by subtracting Vs times a constant from a second constant. These constants are built right into the machine so you'll seldom have to worry about them.

Total range prediction is solved with a couple of cams and multipliers, several differentials, and a few gear ratios to take care of constants. You can see the setup in figure 10–20, which again includes all the component sections you studied in figures 10–9, 10–15, and 10–18 of this chapter.

The key to solving Vs lies in how accurately $R2$ is computed. If $R2$ is correct, then Vs is correct, since Vs is taken from a cam positioned by $R2$. With all its corrections, $R2$ is corrected for wind, own ship and target motion, error due

Digitized by Google

to deflection, and *I.V*. Thus you can say mathematically that

$$R2 = Rt + Rw + Rm + Rx + R.$$

However, only *R* exists separately in actual machines because each multiplier computes two things simultaneously. For example, the range predictor multiplier in figure 10–20 solves *Rw* and *Rt* together—with the inputs *dR*, *Ywr*, and *Tf*—to produce *Rtw*. And the range correction multiplier computes *Rx* and *Rm* together—with the inputs *Ds*, *I.V*., and *R2*—to give *Rmx*. Then *Rtw* and *Rmx* are added

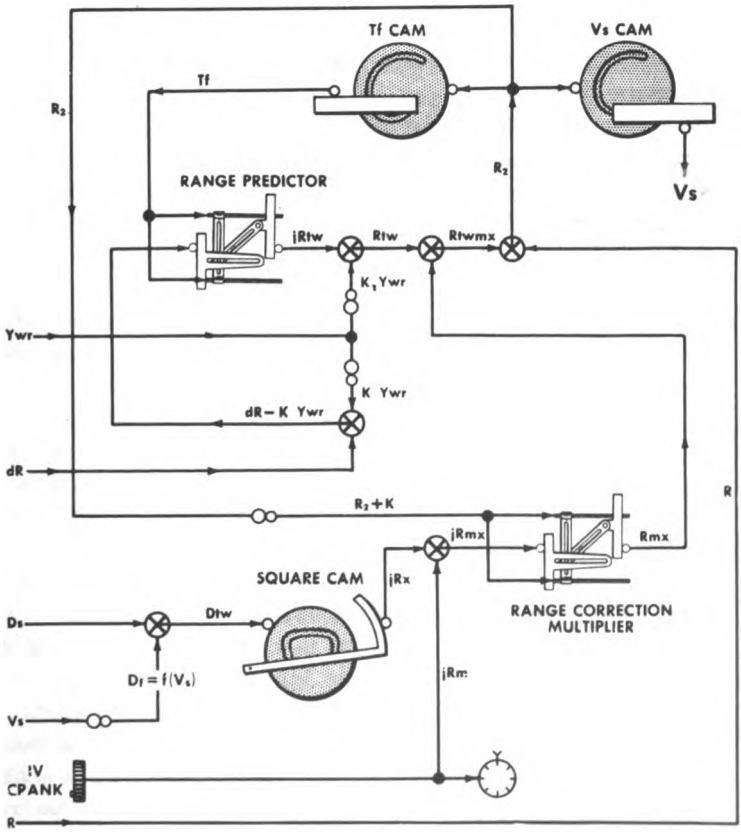


Figure 10–20.—Solving for sight angle *Vs*.

Digitized by Google

in a differential to give TOTAL RANGE PREDICTION, *Rtwmx*.

Finally, the total range prediction, *Rtwmx*, is added to present range *R* in another differential to give advance range *R2*.

You can see from the figure that you're again dealing with that ever-puzzling but useful "vicious circle." Several functions of *R2* are fed back to the inputs to make up corrections in *R2*: A study of the diagram tells you that *Tf*, made from *R2*, helps make up *Rtw*; and that *R2* and *Vs* (also made from *R2*), are fed back to enter into the solution of *Rmx*. It's therefore easy to see that the entire *R2* computer is a regenerative affair. As you work with fire control instruments you'll learn to accept regenerative devices as ordinary gear.

There is one other thing in figure 10–20 that is no doubt puzzling you. That is, it doesn't look right to have both *Ds* and *Vs* as inputs when what you are solving is *Vs*. This is necessary because *Df* is made up as a function of *Vs*. And as you learned in figure 10–15, the partial range correction for deflection, *jRx*, was made by squaring *Dtw*. Since *Ds* contains *Dtw* (remember $Ds = Dtw + Df$), all you have to do to get *Dtw* is subtract *Df* from *Ds* in a differential as indicated in figure 10–20.

Go back to figure 10–20 again and locate the *Vs* cam. *Vs* is not computed directly from a cam as indicated; actually, only a partial value of *Vs* called *jVs*, is computed. Then this partial value of *Vs* is added to the product of *R2* times a constant to give *Vs*.

You can see the true *Vs* curve in figure 10–21A—it is the heavy lined curve, and is plotted against values of *R2*.

Now if all values of *Vs* were to be computed in a cam, the cam would have to be extremely large to be accurate. So in order to use a smaller cam, a STRAIGHT LINE APPROXIMATION of *Vs* is computed by multiplying *R2* by a constant in a gear ratio as shown in figure 10–21B. When plotted, $K \times R2$ produces the straight line approximation indicated in figure 10–21A.

Digitized by Google

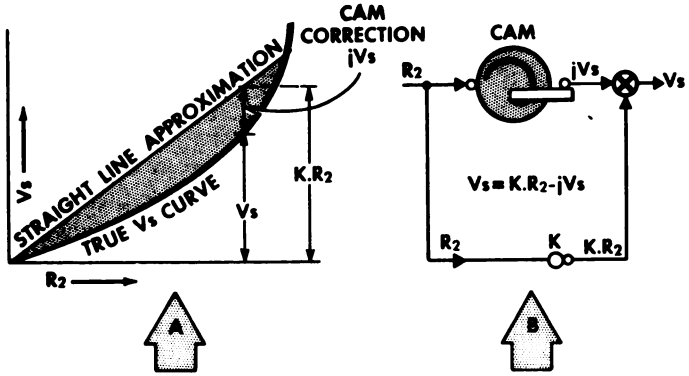


Figure 10–21.—Computing Vs from a straight line approximation.

Then the cam solves the distance between the two curves (the shaded area), corresponding to various *R2* values, which is the difference (*jVs*) between the straight line and the true *Vs* curve. This difference value of *jVs* is then subtracted from the straight line approximation, $K \times R2$, in the differential to give *Vs*. (See fig. 10–21B.)

Vs is not the only function of *R2* that is computed by the use of a straight line approximation—among others, *Tf* is computed in exactly the same way.

Now that you've completed your study of the Siamese twins —*Vs* and *Ds*—you ought to feel relieved. But, ask yourself, do you really KNOW *Vs* and *Ds*? Well, to be frank, you are not expected to have memorized how *Vs* and *Ds* are computed, but you SHOULD be able to trace a blueprint of a surface rangekeeper to see how these two quantities are made up without any trouble. And here's a test which will tell you whether or not you can: Go to figure 10–22 and trace out the entire print.

The best way to trace out any schematic diagram is to start with the inputs, and then work on through the print to the outputs taking one quantity at a time. The inputs in figure 10–22 are shown in circles. You'll notice that most of the constants that were mentioned as each section was discussed in detail are left out. Most constants that are not

Digitized by Google

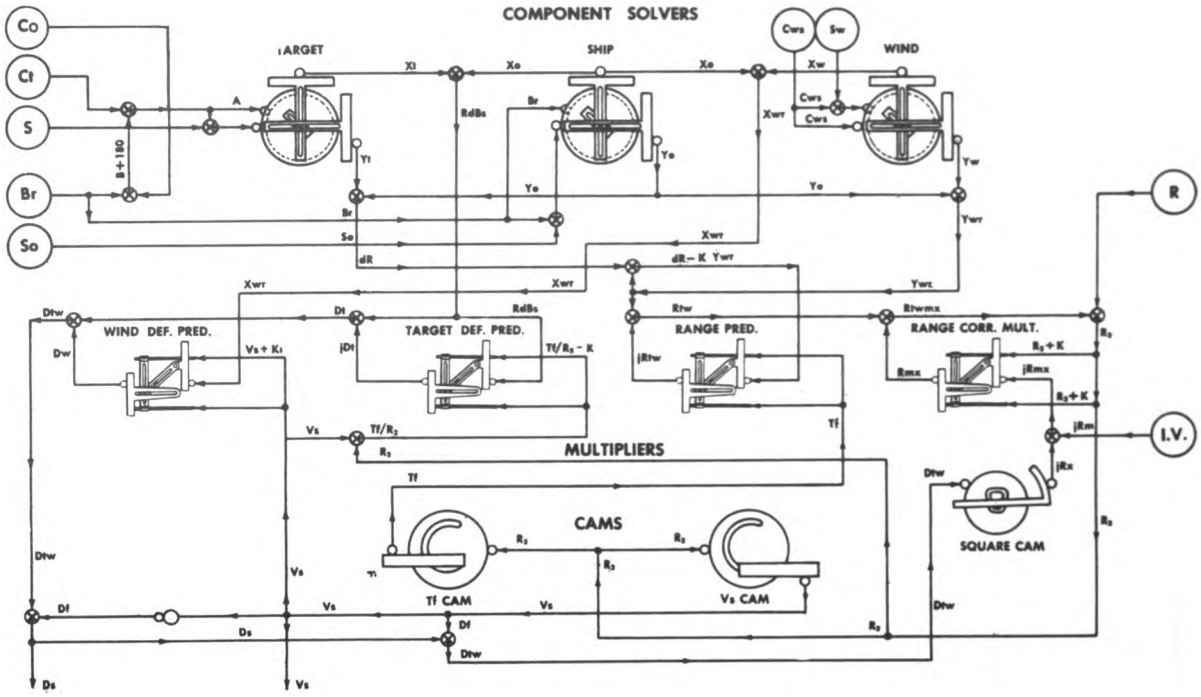


Figure 10–22.—Simplified ballistic computer similar to those used in surface rangekeepers.

Digitized by Google

important to adjustment information are purposely left out in actual prints, so right now is a good time to get accustomed to working without them. However, if you need more detailed information about figure 10–22, go to the index and find out where the section you're in doubt about is located, and then study it carefully.

In all rangekeeper computations thus far it has been assumed that basic quantities, such as *Br*, are always measured in the true horizontal plane. However, the ship is always rolling and pitching, which means that a continuous correction must be added to director train to give *Br*. You'll see how the STABLE VERTICLAL does this in the following chapter.

QUIZ

From the following select the answer (*a*, *b*, *c*, or *d*) which BEST completes the statement or answers the question.

1. If own ship is moving toward the target, which one of the following quantities decreases?
   (*a*) *Ds*.
   (*b*) *RdBs*.
   (*c*) *dR*.
   (*d*) *Vs*.
2. If own ship is moving leftward relative to the target, which one of the following quantities will require a right correction?
   (*a*) *R2*.
   (*b*) *Ds*.
   (*c*) *dR*.
   (*d*) *Df*.
3. The deflection component due to own ship movement is calculated by multiplying
   (*a*) *Xt* by cos *Br*.
   (*b*) *So* by cos *Br*.
   (*c*) *So* by sin *Br*.
   (*d*) *Co* by sin *Br*.
4. The outputs of the own ship component solver are
   (*a*) *Xt* and *Yt*.
   (*b*) *Xo* and *Yo*.
   (*c*) *Br* and *So*.
   (*d*) *Co* and *So*.

Digitized by Google

5. The outputs of the target component solver are
   (*a*) *Xt* and *Yt*.
   (*b*) *Xo* and *Yo*.
   (*c*) *Br* and *Co*.
   (*d*) *A* and *S*.
6. *A* is added to *S* in a differential at the vector input of the target component solver to prevent
   (*a*) the vector input from changing when the angle gear is rotated.
   (*b*) back lash at the vector input.
   (*c*) the angle input from changing when the vector gear is rotated.
   (*d*) the angle gear from slipping when the vector input is rotated.
7. Which of the following quantities tells the speed with which range is changing due to own ship and target motion?
   (*a*) $\frac{Tf}{R2}$.
   (*b*) *RdBs*.
   (*c*) *dR*.
   (*d*) $Tf(Yo+Yt)$.
8. $(Xo+Xt)$ yards/second gives
   (*a*) *jRm*.
   (*b*) *RdBs*.
   (*c*) *Dt*.
   (*d*) *dR*.
9. *jRmω* is multiplied by which one of the following to give *Rmω*?
   (*a*) *jRx*.
   (*b*) *R2*.
   (*b*) $\frac{Tf}{R2}$.
   (*d*) *jRm*.
10. *Dt* is equal to
   (*a*) $RdBs \times 3.43 \times 0.563 \times Tf$.
   (*b*) $\frac{Tf}{R2} \times RdBs \times 0.563 \times 3.416$
   (*c*) $RdBs \times Tf \times dR$.
   (*d*) $\frac{RdBs \times Tf}{R2}$.

Digitized by Google

11. If own ship is making 10 knots with no actual wind present, head-wind speed is equal to
    (*a*) −10 knots.
    (*b*) +10 knots.
    (*c*) zero.
12. *Xwr*=*Xw*+*Xo*=component of apparent wind velocity
    (*a*) Across the line of fire.
    (*b*) Along the line of fire.
    (*c*) Across the line of sight.
    (*d*) Along the line of sight.
13. *Ds* is equal to the sum of
    (*a*) *Dt* and *Dw*.
    (*b*) *Dtwj* and *Dw*.
    (*c*) *Dt*, *Dw*, and *Df*.
    (*d*) *RdBs*, *Dt*, and *Df*.
14. When total range prediction (*Rtwmx*) is added to present range you get
    (*a*) *Vs*.
    (*b*) *dR*.
    (*c*) *RdBs*.
    (*d*) *R2*.
15. Check the following quantities which will NOT cause *Vs* to be in error.
    (*a*) *Rt*.
    (*b*) Yo.
    (*c*) *Dtw*.
    (*d*) *R*.
    (*e*) *Rtwmx*.
    (*f*) *I.V.* setting.
    (*g*) *Tf*.
    (*h*) None of the above.

Digitized by Google

Digitized by Google

CHAPTER 11

DECK AND TRUNNION TILT

Roll and pitch are compensated for by means of a STABLE VERTICAL or by a STABLE ELEMENT. A sketch of a typical main battery setup, employing a stable vertical, is shown in figure 11–1. Although the measurements performed by the stable element and stable vertical are quite similar, only those pertaining to the stable vertical will be discussed in this chapter.

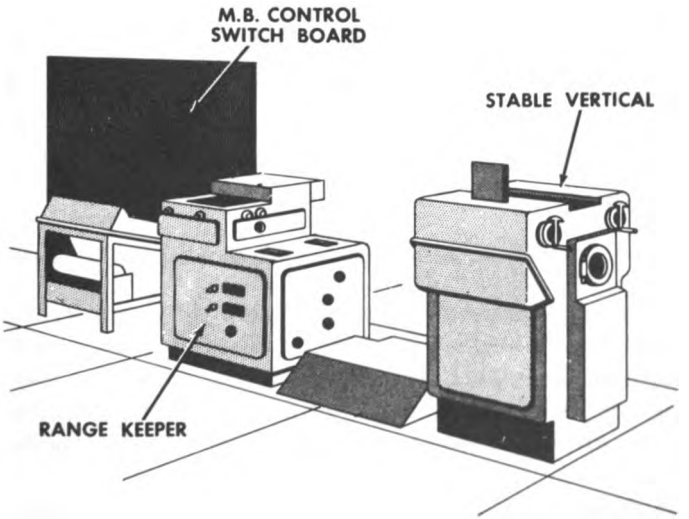


Figure 11–1.—Layout of a main battery plotting room.

Digitized by Google

The stable vertical has two important jobs: DECK TILT CORRECTION and TRUNNION TILT CORRECTION. The purpose of deck tilt correction is to establish a true horizontal plane in the rangekeeper for the computation of all ballistic corrections (Vs and Ds). The purpose of trunnion tilt correction is to modify the gun train and elevation orders, which are made up by the rangekeeper, to compensate for the tilt of the gun trunnions.

LEVEL AND CROSS LEVEL

If you were a director pointer or a director trainer sighting on the target through a telescope with no optical corrections present, the target would appear to move with respect to the telescope crosswire as indicated in figure 11–2. If the ship were tilted in a vertical plane containing the LOS, the target would appear to be under or over the horizontal crosswire as indicated in the left view of the target in figure 11–2. The angle by which the crosswire intersection is displaced VERTICALLY from the target is called the LEVEL ANGLE.

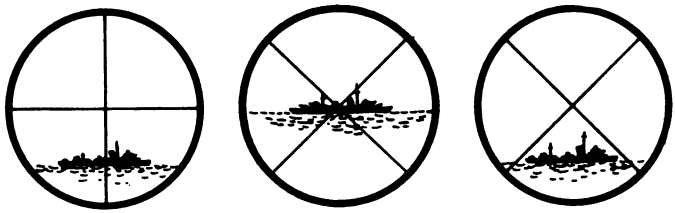


Figure 11–2.—What the pointer and trainer observe through their telescopes.

Looking at it another way, if the ship tilts around the LOS as shown in the center view of figure 11–2, the crosswires will remain on target, but they will appear to rotate one way or the other. The angle, measured in a VERTICAL plane ACROSS the LOS, made by the horizontal crosswire and the true horizontal, is called CROSS LEVEL.

With both level and cross level present, you would see the target through the crosswires as shown in the right drawing

Digitized by Google

of figure 11–2. Notice that the telescope crosswires are displaced vertically as a result of level, and rotated around the LOS as a result of cross level.

Like all other computations we have made so far, the LOS is the reference line for measuring level and cross level. As shown in figure 11–3, the level angle is measured in a VERTICAL PLANE CONTAINING THE LOS. The cross level angle is measured in a VERTICAL PLANE AT RIGHT ANGLES TO THE LOS.

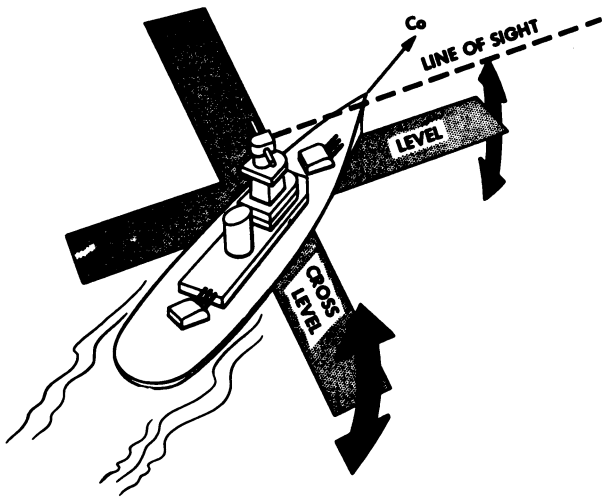
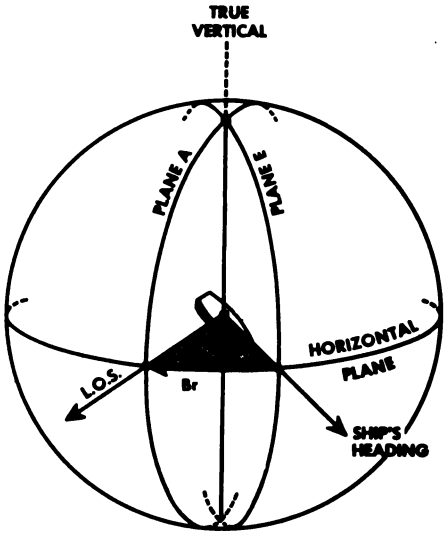


Figure 11–3.—The level and cross level angles are measured in respect to the LOS in vertical planes indicated by the arrows.

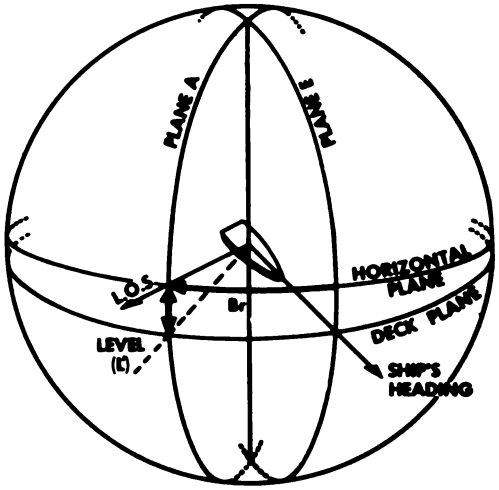
To fully describe the level and cross level angles as measured by the stable vertical, it is necessary to look into spherical diagrams, like the one in figure 11–4, and study the angles between certain planes INSIDE the sphere for different tilts of the ship's deck. The drawing in figure 11–4 is a basic spherical diagram which illustrates the situation when the deck coincides with the horizontal plane. Notice that the director LOS is positioned through the angle *Br* (relative target bearing) from plane E to plane A. When the ship's deck is level, neither level nor cross level is present.

Digitized by Google



PLANE A VERTICAL PLANE CONTAINING L.O.S.
PLANE E VERTICAL PLANE THROUGH CENTERLINE OF SHIP

Figure 11–4.—When the deck is level (coincides with the horizontal plane as shown) no LEVEL or CROSS LEVEL is present.



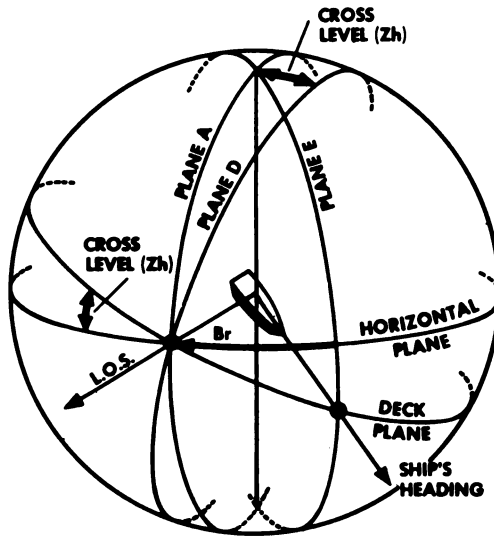
PLANE A VERTICAL PLANE CONTAINING L.O.S.
PLANE E VERTICAL PLANE THROUGH CENTERLINE OF SHIP

Figure 11–5.—When the deck is tilted as shown, only LEVEL is present.

Digitized by Google

But when the ship's deck is tilted, as shown in figure 11–5, so that all the tilt is in the plane containing LOS, only LEVEL (L') is present. You can see that L' would displace the LOS to a point below the horizontal (see the dotted line in fig. 11–5). Of course, a tilt of the ship's deck in the opposite direction would move the LOS above the horizontal. Look at it this way—the gun must be elevated to compensate for level when the deck is tilted as shown in figure 11–5. On the other hand, if the deck is tilted in the opposite direction, the gun must be depressed to correct for level.

Now imagine that the deck of the ship is tilted across the LOS as shown in figure 11–6. The angle that plane D makes with plane A is CROSS LEVEL (Zh). Notice that Zh has no tendency to displace the LOS in the absence of L'.

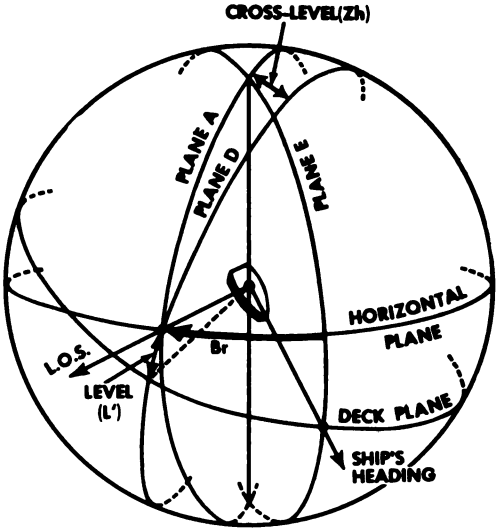


PLANE A VERTICAL PLANE CONTAINING L.O.S.
PLANE D PLANE PERPENDICULAR TO DECK PLANE CONTAINING L.O.S.
PLANE E VERTICAL PLANE THROUGH CENTERLINE OF SHIP

Figure 11–6.—When the deck is tilted around (across) the LOS, without displacing it vertically as shown, only CROSS LEVEL is present.

Digitized by Google

Figure 11–7 shows what happens when both level and cross level are present. A study of the diagram shows that if no corrections were made, the LOS would be displaced below the horizontal plane as indicated by the dotted line.



PLANE A VERTICAL PLANE CONTAINING L.O.S.
PLANE D PLANE PERPENDICULAR TO DECK PLANE CONTAINING L.O.S.
PLANE E VERTICAL PLANE THROUGH CENTERLINE OF SHIP

Figure 11–7.—When the deck is tilted ACROSS and IN the LOS as shown here, both LEVEL and CROSS LEVEL are present.

Summing up, level and cross level are ERRORS caused by the roll and pitch of the ship, and they must be corrected to get hits. Briefly, the stable vertical measures these errors and transmits their corresponding corrections (L' and Zh) to the rangekeeper to enter into the computations of the gun orders. Before leaving this section be sure you understand that L' is measured in a VERTICAL PLANE containing the LOS, and Zh is measured as tilt ACROSS the LOS: otherwise, a

Digitized by Google

thorough understanding of what the stable element does will be difficult.

You'll recall that the stable vertical consists primarily of a high-speed gyro which spins in the vertical plane, and is kept in the vertical plane by the latitude correction and gimbal rotation righting forces. Thus, the gyro spins in the true vertical at all times and the ship appears to tilt about the gyro. Consequently, it provides an excellent means of measuring level (L') and cross level (Zh).

You can get an idea of how the stable vertical does its job in figure 11–8. If the gyro is always oriented so that one gimbal axis remains in the LOS and the other across the LOS as indicated, the tilt of the gyro in the vertical plane containing the LOS will measure level, whereas the gyro tilt across the LOS will measure cross level.

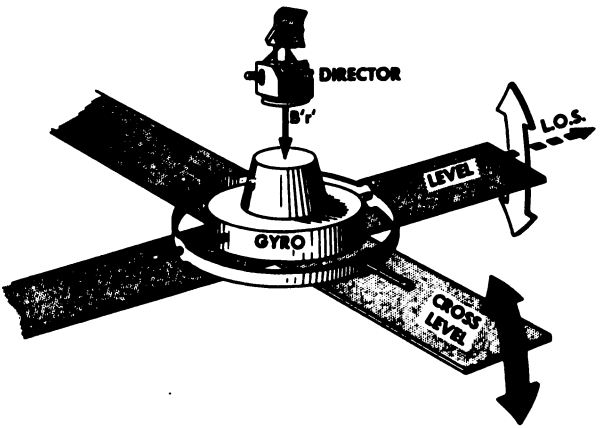


Figure 11–8.—The gyro measures level and cross level.

The stable vertical does all this with only one input—director train ($B'r'$). If you stop to think, you'll remember that $B'r'$ is relative target bearing as measured by the train of the director in the deck plane of the ship. Thus, as the director is trained from the ship's center line around to the LOS, it trains through the angle $B'r'$. Therefore, director

Digitized by Google

train establishes the LOS. In short, to position the gyro gimbals relative to the LOS as shown in figure 11–8, $B'r'$ is transmitted to the stable vertical from the director.

Let's examine the stable vertical more closely. Figure 11–9 shows a simplified stable vertical placed outside of its case and mounted on a ship. The figure also shows the names of the various major parts. $B'r'$ is received electrically from the director by synchro transmission and a servo follow-up motor. The servo (not shown) drives the training shaft.

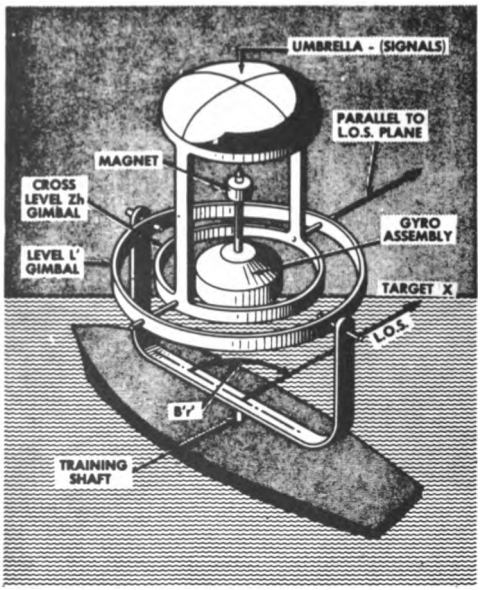


Figure 11–9.—Simplified stable vertical schematic diagram.

On top of the gyro assembly is mounted a magnet which is energized with 115-volt a. c. from the fire control switchboard. An umbrella (a set of electrical figure-eight coils—one for level and one for cross level) is mounted on the cross level gimbal as shown in figure 11–10.

When the ship is perfectly stable (horizontal), the magnet

Digitized by Google

points directly at the intersection of the lines on the umbrella. But if the ship is tilted, the gimbal assembly and fork roll around the gyro, and the magnet points at some other point on the umbrella. This produces a voltage of a certain a-c polarity in the umbrella coils. This voltage is then amplified and fed to a set of electric follow-up motors (one for level and another for cross level) which reposition the level and cross level gimbals so that the center of the umbrella is again exactly over the magnet. (See fig. 11–10.)

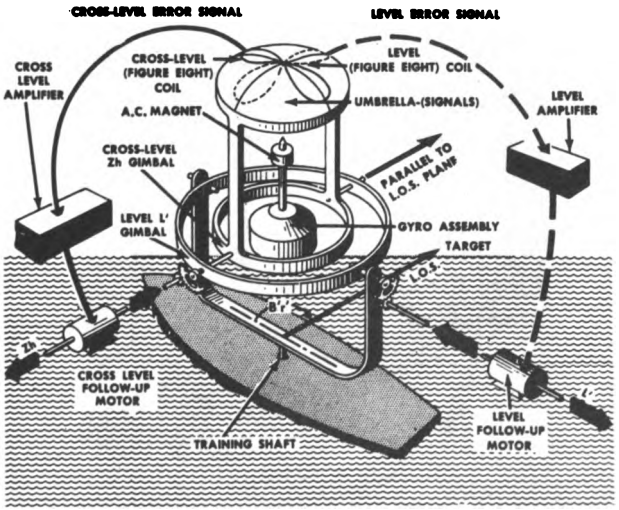


Figure 11–10.—Stable vertical follow-up control assembly.

As soon as the umbrella is over the magnet, the net voltage in its coils becomes zero and the follow-up motors stop. Therefore, in repositioning the umbrella, the level and cross level follow-up motors have driven out the L' and Zh angles at their shafts.

How the Stable Vertical Measures Level

In figure 11–11 the deck has tilted so that all of the motion is about the level axis; that is, motion is about the pivots of

Digitized by Google

the outer or level gimbal on the supporting fork. This displacement about the level axis is the LEVEL ERROR.

When the deck is inclined as shown in figure 11–11, the outer (level) gimbal initially partakes of deck motion, and the umbrella moves with respect to the a-c magnet, which is maintained in the vertical by the gyro. An electrical signal

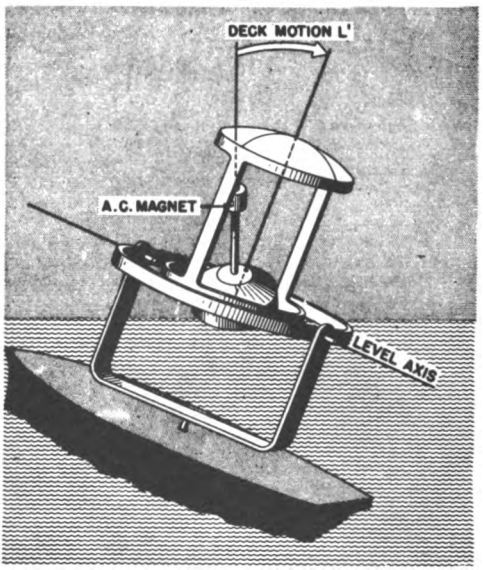


Figure 11–11.—Level error.

is now generated in the level figure-eight coil. This signal is amplified by the level amplifier (fig. 11–10), whose output excites the level follow-up motor. As the motor drives, it repositions the level gimbal so that the umbrella is again centered over the a-c magnet.

In figure 11–12 the instrument is pictured as it would look AFTER the level motor has restored the level gimbal to the horizontal. The motion of this gimbal is therefore a measure of L', which appears as a shaft position at the level follow-up motor.

Note carefully that the level gimbal is mounted in the fork,

Digitized by Google

which is in turn supported by the deck. Thus the level axis is always kept parallel to the deck by the level follow-up motor. The level angle is always measured in a plane, containing the LOS, perpendicular to the deck. It should also be noted that by leveling the level gimbal, the cross level pivots of the inner gimbal are brought back to the horizontal. As a result, the cross level axis is always kept horizontal as shown in figure 11–12.

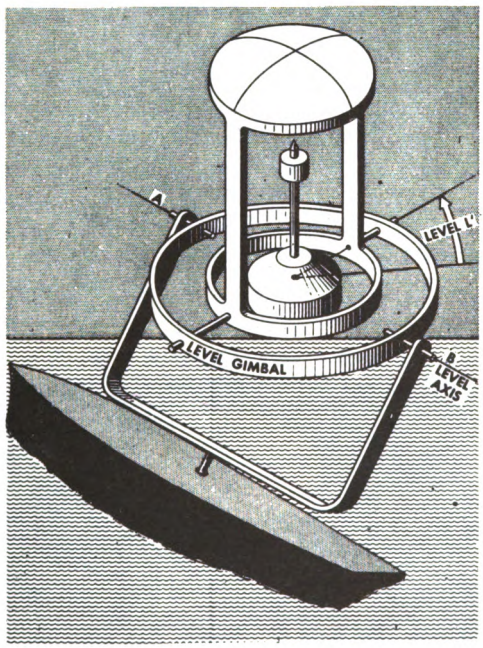


Figure 11–12.—Level angle after measurement.

How the Stable Vertical Measures Cross Level

Cross level is measured differently than level, because the cross level error is defined in a vertical plane at right angles to the LOS. In figure 11–13, deck motion is all in cross level. That is, the ship is inclined so that the entire assembly is rotated about the cross level or Zh axis. Notice that the Zh

Digitized by Google

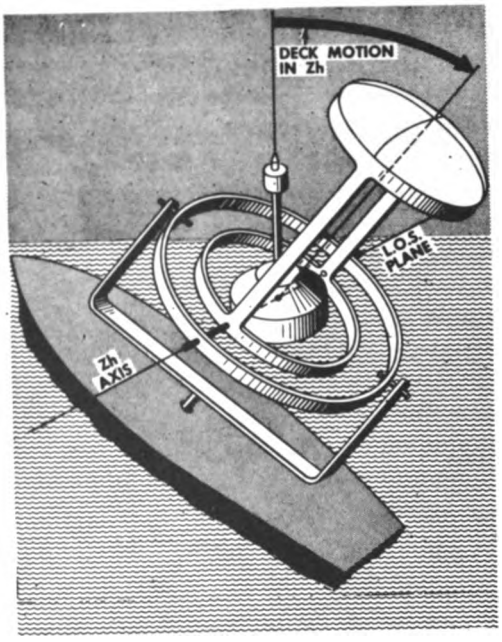


Figure 11–13.—Cross level error.

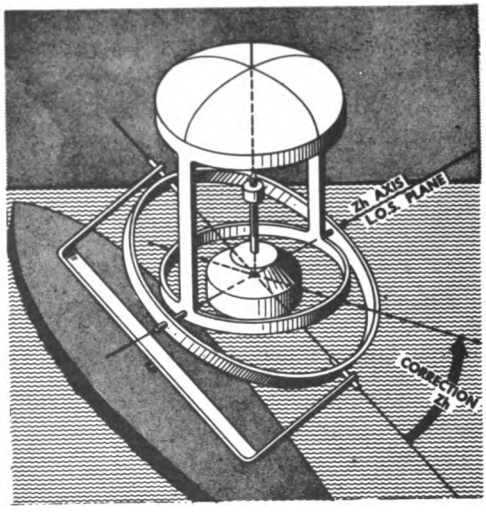


Figure 11–14.—Cross level angle after measurement.

Digitized by Google

axis always lies in line with the LOS, and even though the whole assembly is tilted about this axis, no tilt occurs about the level axis. Thus the umbrella in this case is displaced only by cross level.

As soon as the umbrella partakes of the cross level motion, a voltage is induced in the cross level figure-eight coils, which control the cross level follow-up motor (see fig. 11–10). This causes the motor to drive the cross level gimbal until the umbrella is again centered over the magnet, and the umbrella signal again falls to zero causing the motor to stop as shown in figure 11–14. Of course, in driving the cross level gimbal and umbrella back to the neutral position, the motor shaft also turns an amount proportional to Zh. And like L', Zh appears as a motor shaft position which is fed to the rangekeeper.

Measuring L' and Zh at the Director

In the event of stable vertical failure, the main battery director takes over the job of measuring L' and Zh. A flip of a switch at the fire control switchboard makes the change over. The director pointer measures L' and another operator called the cross leveler measures Zh. Of course, these measurements are subject to human errors, but even so they're handy in an emergency.

As the cross leveler and pointer at the director sight through their sights, they make the corrections with hand wheels. These hand wheels are geared to synchro transmitters, which transmit the measured quantities to the rangekeeper as shown in figure 11–15.

A study of the diagram shows that the L' and Zh quantities measured by the director are received only by the trunnion tilt section at the rangekeeper. The trunnion tilt computer receives L' and Zh electrically as shown. This means that if deck tilt correction is to be used in the event of stable vertical follow-up motor failure, L' and Zh must be cranked in manually at the stable vertical. This is accomplished by the stable vertical operators who crank as they

Digitized by Google

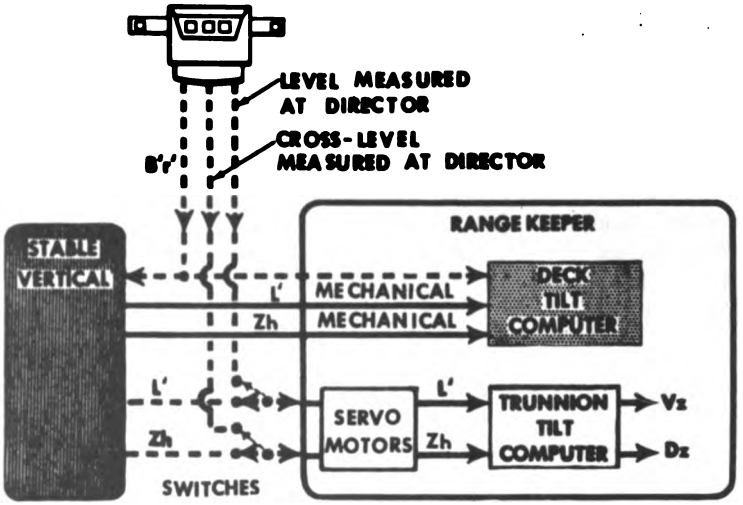


Figure 11–15.—Level and cross level measured by the director and transmitted to the rangekeeper by synchros.

observe the level and cross level dials on the face of the stable verticle. With everything in working order, it is possible for the deck tilt computer to receive L' and Zh automatically from the stable vertical, while the trunnion tilt computer gets its inputs from the director. This provides a split type of control. These different combinations of operation will be more apparent when you work with the gear.

Since you now know how L' and Zh are received at the rangekeeper, the next step is to see how the director does the measuring. Let's take the measurement of L' first.

Imagine that the director is trained out abeam, as shown in figure 11–16, and the pointer and trainer are sighting down the director LOS. The offset of the pointer's telescope from the reference plane (the reference plane is approximately parallel to the ship's deck) to the LOS is called DIRECTOR ELEVATION, $E'b$. When the deck is tilted as shown in figure 11–16, $E'b$ contains L' (the angle between the reference plane and the horizontal at either the director or gun) and the director SIGHT DEPRESSION ANGLE.

Digitized by Google

Now, since $E'b$ contains L', it should be apparent that all you have to do to get L' is subtract the depression angle from $E'b$. But it isn't that simple because the sight depression angle must first be computed. Look at figure 11–16 and try to visualize what would take place if the director and gun were located at the same level. Obviously, the director depression angle would then equal L'. Thus, the vertical distance of the director above the gun is what causes the trouble. The difficulty is that the director and gun lines of sight are not parallel. Instead, they converge on the target at an angle known as VERTICAL PARALLAX, Pv. Vertical parallax is affected by the vertical distance between the gun and director, as well as by the range to the target. The computation of vertical parallax will be covered in the next chapter.

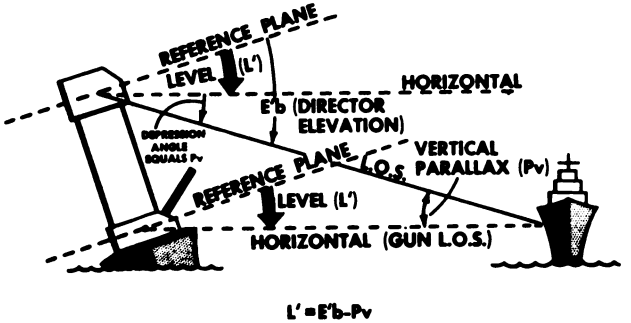


Figure 11–16.—How the director measures level.

A further study of figure 11–16 will indicate that the director LOS can be thought of as a transversal cutting through two parallel lines (the horizontal lines at director and gun). Thus, the alternate-interior angles formed by the LOS and these horizontal lines are equal, i. e., the director sight depression angle is equal to Pv. Therefore, if Pv is manufactured in a mechanism at the director and subtracted from $E'b$, the director will transmit L' to the rangekeeper as desired.

Digitized by Google

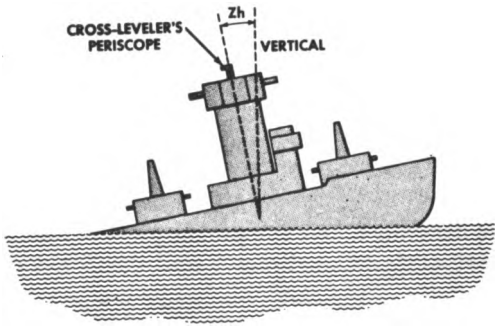


Figure 11–17.—Cross level as measured at the director.

Cross level, shown in figure 11–17, is measured by the cross leveler operator as he keeps his periscope horizontal crosswire on the horizon as indicated in figure 11–18. Since Zh is measured as tilt across the LOS, the cross leveler sights 90° away from the LOS (fig. 11–18). The cross leveler cranks his handwheels as he elevates or depresses his sight to the horizon, and in doing so, positions a synchro transmitter which transmits Zh to the rangekeeper.

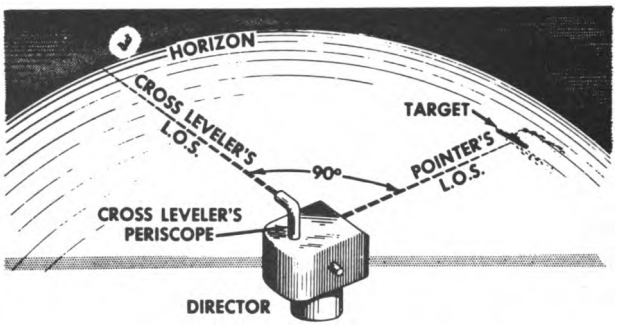


Figure 11–18.—The cross leveler's periscope is positioned 90° away from the LOS to the target.

To sum up, the stable vertical normally feeds L' and Zh to the deck tilt and trunnion tilt computers at the rangekeeper, and the only angular input transmitted from the di-

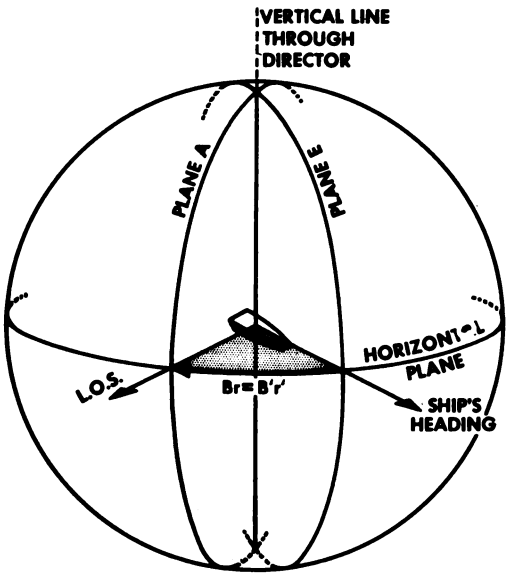
Digitized by Google

rector to the stable vertical and rangekeeper is $B'r'$ (see fig. 11–15). However, in the event of stable vertical failure, the director measures L' and Zh, in addition to $B'r'$, and transmits them to the rangekeeper where they are received by the deck tilt and trunnion tilt computers (see fig. 11–15).

Now that you know how level and cross level are measured, the next big step is to see how they're used in computing the deck tilt and trunnion tilt corrections at the rangekeeper. Both deck tilt and trunnion tilt corrections are extremely important in the computation of fire control problems.

DECK TILT CORRECTION

Thus far you have studied rangekeeper computations with the assumption that the deck of the ship was level. In



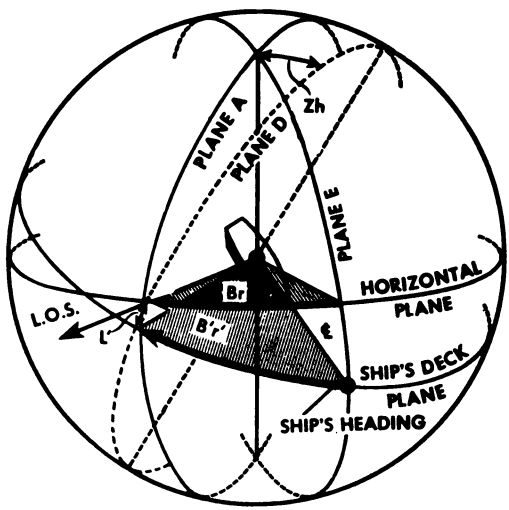
PLANE A— VERTICAL PLANE CONTAINING L.O.S.
PLANE E — VERTICAL PLANE THROUGH CENTERLINE OF SHIP

Figure 11–19.—Relative target bearing *Br* and director train *B'r'* are equal when the deck is horizontal.

Digitized by Google

other words, all computations for own ship and target motion on through *Vs* and *Ds* were made up in the horizontal plane. What you studied was correct, as far as you went. All rangekeeper computations are made in the horizontal plane. And since the director makes its measurements of present target position in the deck plane, some method of stabilization is required to correct for deck tilt.

One of the most common measurements made by surface fire directors is director train, *B'r'*. The measurement of *B'r'* is an indirect way of determining relative target bearing *Br*. *Br* enters into the computations of own ship and target motion. Let's investigate *B'r'* and see how it is converted to *Br* for use in the rangekeeper.



PLANE A VERTICAL PLANE CONTAINING L.O.S.

PLANE E VERTICAL PLANE THROUGH CENTERLINE (℄) OF SHIP

PLANE D PLANE PERPENDICULAR TO DECK PLANE CONTAINING L.O.S.

Figure 11–20.—When the deck is tilted, director train *B'r'* is no longer equal to relative target bearing *Br*.

Digitized by Google

First consider the condition where the deck plane of the ship coincides with the horizontal plane as shown in figure 11–19. You can see that $B'r'$ is measured from the ship's centerline at plane E around to the line of sight at plane A. And since the ship is horizontal, Br is equal to $B'r'$.

But the story becomes different when the ship is tilted. When the deck is tilted through the L' and Zh angles as shown in figure 11–20, the director must be trained farther from the ship's centerline in order to indicate relative target bearing. Obviously, Br is no longer equal to $B'r'$ because $B'r'$ is now larger than Br. This points out the reason why $B'r'$ must be corrected when the deck is tilted, before it can be used by the rangekeeper in solving the own ship range and deflection components. In other words, $B'r'$ is the measurement of relative target bearing in the deck plane, and before it can be used for rangekeeper ballistic calculations which are made in the horizontal plane—it must be referred to the

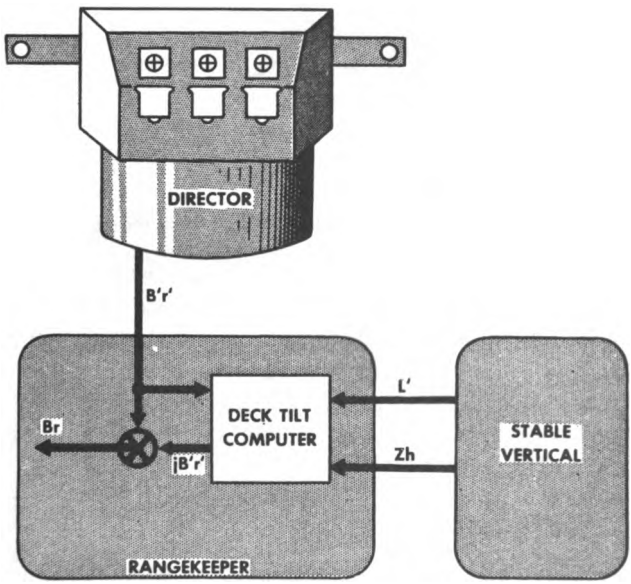
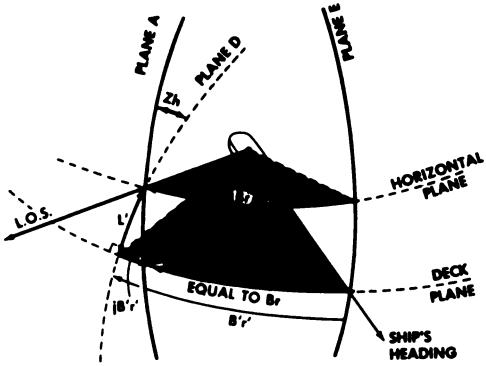


Figure 11–21.—Computing deck tilt correction.

Digitized by Google

horizontal plane. In short, $B'r'$ must be converted to Br.

The job of converting $B'r'$ to Br is performed by the deck tilt computer in the rangekeeper. As shown in figure 11–21, the deck tilt computer calculates a quantity called DECK TILT CORRECTION ($jB'r'$) which is added to $B'r'$ in a differential to give Br. $jB'r'$ is computed from $B'r'$, L', and Zh as shown. Even though its mathematical solution is a little complicated, you can see what part $jB'r'$ plays by studying figure 11–22. This figure is really just a magnified view of figure 11–20, with the $jB'r'$ angle drawn in.



$Br = B'r' - jBr$

Figure 11–22.—When the deck is tilted about the LOS as shown, deck tilt correction $jB'r'$ is subtracted from $B'r'$ to give Br.

A careful study of figure 11–22 will indicate that $jB'r'$ is dependent upon both L' and Zh—the smaller these two angles are, the smaller $jB'r'$ becomes. For the condition shown, $B'r'$ is larger than Br, so the deck tilt correction is subtracted from $B'r'$ to give Br. That is, $Br = B'r' - jB'r'$. However, for certain other values of Zh and L', deck tilt correction is added to $B'r'$ to give Br. Thus, in order to be correct at all times, relative target bearing is given by:

$$Br = B'r' + jB'r'.$$

Digitized by Google

In this way $jB'r'$ can change sign as L' and Zh change signs, and the problem will always work out right.

To get a better picture of how the deck tilt computer fits into the fire control system, look at figure 11–23. Let's go through the diagram step by step, starting at the director. As the director is sighted on the target it measures $B'r'$, which is transmitted to the stable vertical and deck tilt computer in the rangekeeper. Notice also that $B'r'$ feeds into the gun order section; you'll learn about this later. Then the stable vertical measures L' and Zh with reference to the LOS and transmits them to the deck tilt computer. The LOS is established by $B'r'$.

The deck tilt computer then makes up $jB'r'$ from the $B'r'$, L', and Zh inputs, and adds it to $B'r'$ in a differential to give Br (see fig. 11–21).

By definition, Br is relative target bearing measured in the horizontal plane from the bow of own ship clockwise to the LOS. Therefore, the manufacture of Br establishes a true horizontal plane for the calculation of own ship range and deflection components in the linear rates section shown in figure 11–23.

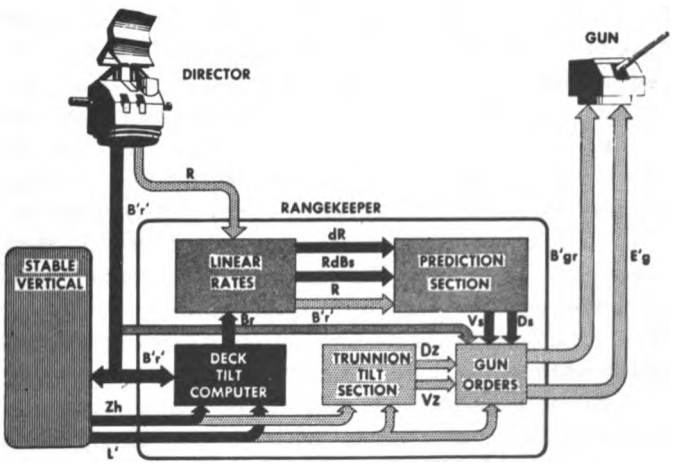


Figure 11–23.—Where the deck tilt computer fits in.

Digitized by Google

The linear rates (*dR* and *RdBs*) are now calculated from the *Br*, *R*, and target inputs. These linear rates become the inputs to the prediction section where *Vs* and *Ds* are made up. As you already know, *Vs* and *Ds* contain all ballistic, wind, and relative motion corrections required to properly position the gun from the horizontal plane. For this reason, *Vs* and *Ds* also are accurate indications of the gun position only when the deck plane and horizontal plane coincide. This is one reason why the trunnion tilt computer is necessary. The trunnion tilt section of the rangekeeper manufactures the *Dz* and *Vz* corrections shown in figure 11–23. These corrections are added to *Vs* and *Ds* in the gun order section where the gun train and elevation orders are made up. You'll learn about trunnion tilt in the section immediately following.

How the Tilted Deck Affects the Gun

The deck tilt of a ship can be considered as having two effects on the aim of a gun. One of these effects is to constantly elevate and depress the gun as a result of the level angle. This is shown in figure 11–24.

You can see from figure 11–24 that in order for the gun to remain in the LOF, *L'* (the correction) is added to *Vs*. When added, *Vs* and *L'* produce gun elevation order *E'g*. *E'g* is the elevation of the gun from the reference plane up to line of fire (LOF). The reference plane is approximately parallel to the deck plane. Of course, the LOF can be thought of as an extended line along which the gun must be fired to hit the target. Thus, in order to keep the gun positioned in the LOF, *L'* is continually added to *Vs*. It should be clear at this point that *Vs* is equal to *E'g* when the deck is level.

When the gun is trained abeam as shown in the upper drawing of figure 11–24, level is entirely dependent upon the roll of the ship and thus is very large. In this position it would be useless to try and fire without correcting gun elevation order by adding in *L'*. As the gun is trained ahead or

Digitized by Google

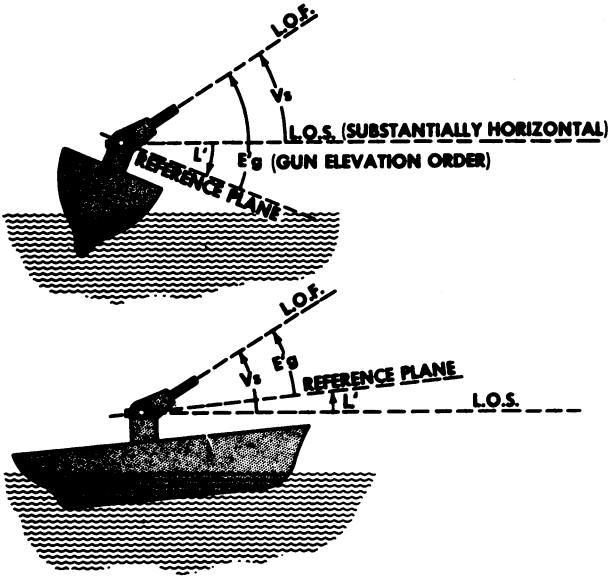


Figure 11–24.—How gun elevation is affected by the level angle.

astern, as shown in the lower drawing, the L' correction angle grows smaller and smaller because it becomes less dependent upon roll and more dependent upon pitch.

So much for level—the whole story is shown in figure 11–24. Level alone has no other influence on the gun than that shown. Gun elevation order is covered in the chapter on gun orders.

A second effect of the ship's movement is the tilt of the gun trunnions sideways. This effect is caused by cross level as shown in figure 11–25.

Even though our discussion has been confined to surface fire, gun elevation above the deck nevertheless presents a problem when Zh is present. Looking at figure 11–25 notice how the elevated gun barrel changes position when the gun trunnion axis is displaced from the horizontal by the angle Zh. Obviously, in order to hit the target, the gun must be trained and elevated back to its dotted-line position.

Digitized by Google

As shown in the upper diagram of figure 11–25, cross level is large for fore or aft shots because it is entirely dependent upon the ship's roll. This, of course, causes large trunnion tilt errors. When the gun is trained abeam, as shown in the lower figure, Zh becomes smaller and smaller, and so do the trunnion tilt errors.

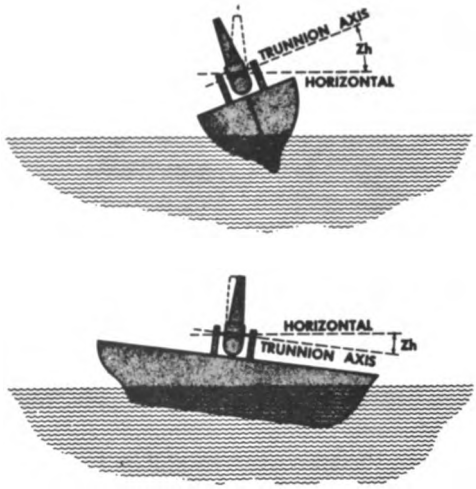


Figure 11–25.—How cross level affects the gun position.

The trunnion tilt errors must be corrected continuously and automatically in order to produce satisfactory results. This is accomplished by the stable vertical and trunnion tilt computer. The trunnion tilt computer constantly feeds corrections into the gun order section of the rangekeeper (fig. 11–23).

Before getting involved in the rangekeeper computations of the trunnion tilt corrections, it is necessary to thoroughly understand the errors caused by trunnion tilt, and their corresponding corrections. These errors and corrections are very similar for all guns. The errors pointed out in figure 11–25 by no means define the solution to the trunnion tilt problem, they simply show what the errors are. A more detailed explanation follows.

Digitized by Google

TRUNNION TILT ERRORS

Firing without regard to trunnion tilt can result in large errors, especially in deflection. Roughly speaking, the deflection error in mils for surface fire is approximately one-third of the product of Vs and Zh. Thus, if the gun is fired at an elevation of 20° with the deck tilted so that Zh is 6°, the deflection error would be about 40 mils; that is $\frac{20 \times 6}{3} = 40$ mils. At a firing range of 15,000 yards this is equivalent to a deflection error of 600 yards, or approximately one-third of a mile!

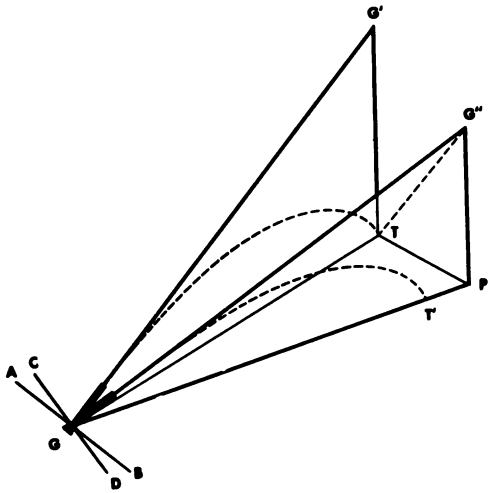


Figure 11–26.—Trunnion tilt errors.

You can see the effect of trunnion tilt for surface fire in figure 11–26. GG′ represents the axis of the bore of the gun when the trunnion axis AB is horizontal. In this case, if we assume that there are no deflection and no drift present, the trajectory GT will lie in the plane GG′T. The angle of elevation for the gun to hit the target will be TGG′.

Now if the axis of the trunnion is tilted through the angle AGC, the axis of the bore of the gun will lie along the line

Digitized by Google

GG″ instead of GG′, and the angle G′TG″ will be equal to the trunnion tilt AGC. The trajectory will now lie in the vertical plane GG″P through the axis of the bore of the gun, GG″. Therefore, the projectile will land at the point T′.

We see that two errors result. An inspection of figure 11–26 shows that the first error is the deflection error TP. The other error is a range error PT′, which is caused by the decreased gun elevation angle. Therefore the projectile will fall away from the target by the amount TT′.

A study of figure 11–27 can tell you several other things about trunnion tilt errors. First, notice that as Zh increases, the elevation of the gun decreases—in fact, if the trunnions were tilted at right angles to the horizontal the gun elevation would become zero. You can therefore conclude that range errors increase as trunnion tilt increases.

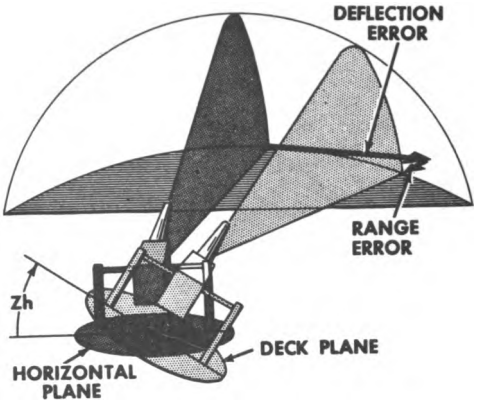


Figure 11–27.—Effect of trunnion tilt.

Also, a study of figure 11–27 shows that the deflection error will vary with the gun elevation and range. We find that deflection errors due to trunnion tilt increase with range. At point blank range where the trajectory is perfectly flat (zero gun elevation), the deflection error will be zero regardless of how large trunnion tilt becomes. The bore axis

Digitized by Google

will still point in the same direction no matter how far the gun trunnions, and in turn the bore, are rotated.

In considering the trunnion tilt errors indicated in figure 11–27, note that when the trunnions are tilted through the angle Zh you get a deflection error and a range error. Deflection errors will always be large because of gun elevation, and therefore are always compensated. However, range errors are usually very small, because the tilt caused by Zh has only a slight effect on gun elevation. Thus range errors are sometimes ignored for surface fire. Obviously, the tilt and resulting errors indicated in figure 11–27 are greatly exaggerated.

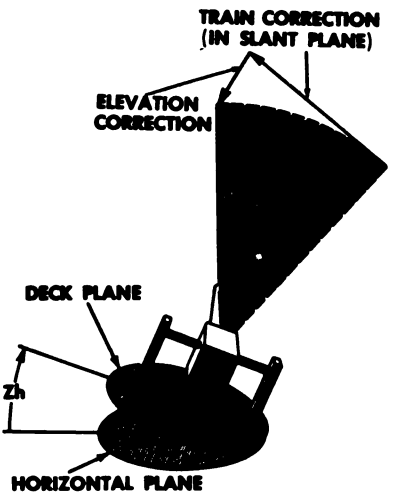


Figure 11–28.—Correction for trunnion tilt.

In order to correct the errors shown in figure 11–27, the gun must be trained uphill to the right, and depressed back on the target as indicated in figure 11–28. You can see that, although the error caused by trunnion tilt is largely a deflection error, its correction requires motion of the gun in both train and elevation. These corrections are called the train correction in the slant plane due to trunnion tilt, and the

Digitized by Google

elevation correction for trunnion tilt in a plane perpendicular to the deck through the bore axis. These are the corrections called trunnion tilt train correction *Dz*, and trunnion tilt elevation correction *Vz*.

Trunnion Tilt Errors and Corrections With No Deflection Present

The only way you can thoroughly understand trunnion tilt errors and their corrections is to study how they vary under different conditions. Mathematical explanations grow too involved for this course, but you can learn all you need to know about trunnion tilt from spherical diagrams. These diagrams will tell you exactly how trunnion tilt errors vary for different deck tilt angles and gun elevations.

Back in figures 11–27 and 11–28, you learned about the errors and corrections that occur when the LOF and the LOS coincide. Also, own ship and target were assumed to be stationary. A more complete description will now be presented for the same set of conditions, with the use of spherical diagrams.

Figure 11–29 shows the horizontal and vertical planes. The horizontal plane is always stationary and remains tangent to the earth's surface. The vertical plane is always perpendicular to the horizontal plane, and always contains the LOS; it shifts with the relative target bearing angle, *Br*. The gun is at O and the target at T, making the LOS correspond to the line OT. Since no deflection is present, the director and gun lines of sight coincide. The relative target bearing *Br* of the LOS is also shown on the diagram. Although *Br* is used to determine the LOS relative to the ship's head, for simplicity it is not shown in the following diagrams. It should be borne in mind, however, that the LOS is the reference for measuring *L'* and *Zh*, and therefore is of vital significance.

In figure 11–29 the ship's deck is horizontal, and so the deck plane corresponds to the horizontal plane. But in figure 11–30 the deck plane is tilted by the angle *Zh* about

Digitized by Google

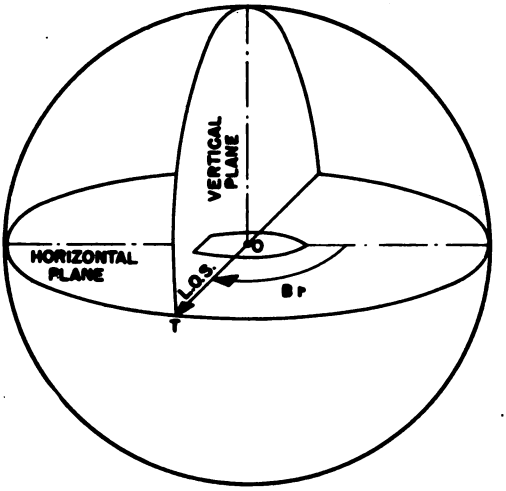


Figure 11–29.—Basic spherical diagram.

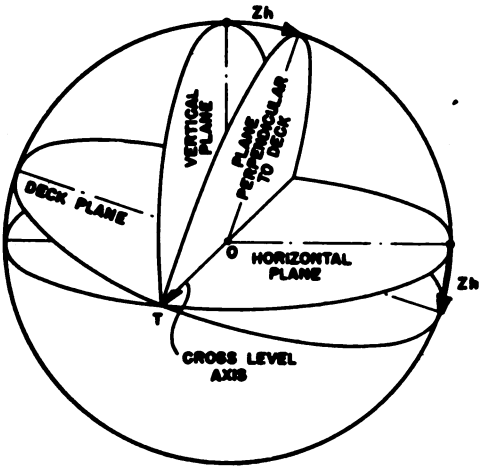


Figure 11–30.—Cross level (surface problem).

Digitized by Google

the line OT, the cross level axis (LOS). Therefore, if the bore axis of the gun were elevated in the vertical plane with the deck horizontal, it would be carried over to the vertical plane perpendicular to the deck, which is displaced from the true vertical plane by the angle Zh. Thus, the LOF will be displaced from the vertical plane containing the LOS.

This displacement of the LOF can be clearly understood from figure 11–31. The line OE represents the initial or computed position of the LOF, with no deflection present. The gun initially lies in the vertical plane containing the line of sight OT, and is elevated above the deck plane (which coincides with the horizontal plane) by the angle $E'g$ (gun elevation order) to the position OE.

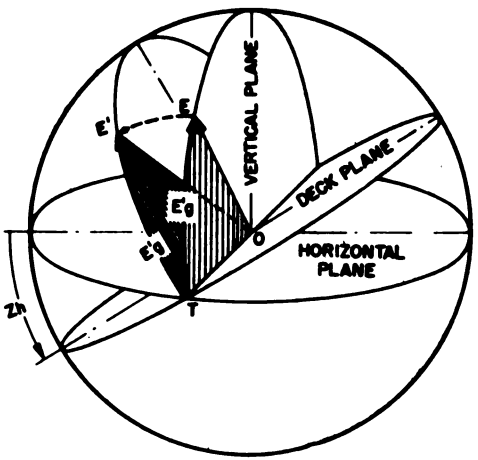


Figure 11–31.—Error due to trunnion tilt with no deflection.

Now assume that the deck plane becomes inclined about the axis OT by an amount equal to pure cross level as shown in figure 11–31. This will swing the LOF from OE to OE′, lowering the gun aim and also creating a large angular error in deflection. Of course, until a correction is applied, the mere inclination of the deck will have no effect upon the angle the gun is elevated above the deck. The gun will be

Digitized by Google

firing at a false point E', until the computed angle $E'g$ is corrected.

Now refer to figure 11–32; the left diagram illustrates the corrections for the errors which were illustrated in figure 11–31. Let's first assume that you want to correct the deflection error. You know that the gun's roller path lies in the deck plane so that when it trains back to get from its present position E′ to the computed point of aim E, the projection of the LOF on the sphere will swing in an arc parallel to the deck plane. This motion is represented by the train correction a, which is an angular correction in the slant plane.

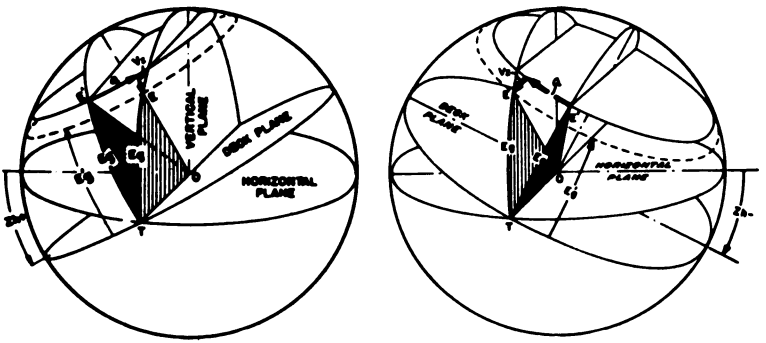


Figure 11–32.—Correction for trunnion tilt with no deflection.

As can be readily seen in the figure, the train correction a in the slant plane is not enough to completely correct the gun for Zh because it leaves the gun axis above the point E. The elevation correction Vz is required to completely solve the problem.

The right drawing in figure 11–32 illustrates the nature of the corrections for a Zh of the opposite or negative direction. Notice that the corrections are similar in the case where no sight deflection is present, and that the elevation correction Vz is always down.

Figure 11–33 repeats the situation shown in the right drawing of figure 11–32 with an additional angle shown. It shows how train correction a in the slant plane is converted

Digitized by Google

to the corresponding gun train correction, *Dz*, in the deck plane. In figure 11–33, *Zh* initially caused the gun bore to move to point E′. A study of the figure shows that the train correction *a* and the elevation correction *Vz*, both in the slant plane, have restored the gun to position *E* in space.

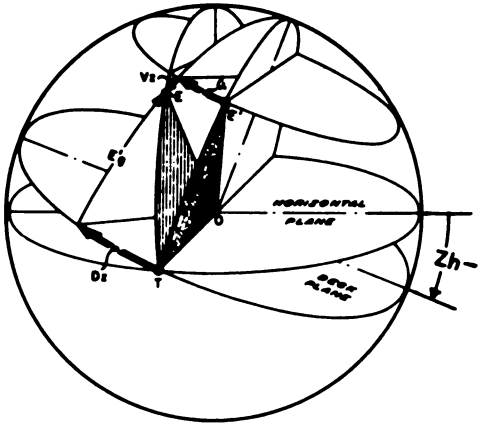


Figure 11–33.—Converting train correction *a* in the slant plane into train correction *Dz* in the deck plane.

To form a reference, the vertical plane through the LOS is drawn in. With no sight deflection present, the LOS represents the computed train of the LOF. However, as described previously, even though we have computed a deflection (zero in this case) to allow for the ballistics, we need an additional gun train correction in the deck plane to compensate for trunnion tilt.

The train correction, *a*, presents a problem because it is located in the slant plane containing the LOF. (See fig. 11–33.) The gun must be trained through the angle *Dz* in the deck plane of the ship to correct for the train error *a* in the slant plane.

Figure 11–34 shows how the train correction *a* and elevation correction *Vz* vary with the gun elevation. If the gun axis is lying along OT, no correction is required, but as the

Digitized by Google

gun elevates both a and Vz grow larger and larger. You can therefore say, since gun elevation depends on sight angle Vs, the trunnion tilt corrections increase as sight angle increases. Obviously Dz grows larger as a grows larger. Dz also increases with sight angle.

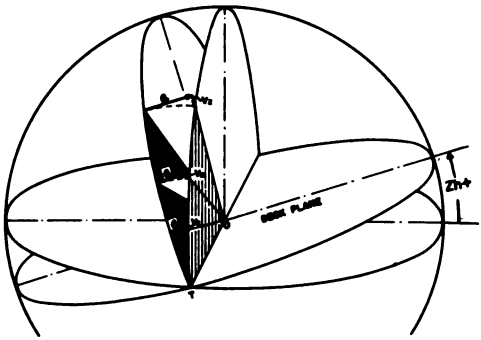


Figure 11–34.—The correction a and Vz increase as sight angle increases.

Trunion Tilt Corrections With Sight Deflection Present

The introduction of sight deflection Ds makes the problem a little more complicated in that Dz and Vz both vary as Ds varies. It is therefore evident that trunnion tilt corrections must take both Vs and Ds into account when being computed.

Figure 11–35 shows the situation where the deck is horizontal. The horizontal line of sight OT is shown, but for clarity the vertical plane through the LOS has been omitted. Sight deflection Ds in the horizontal plane (which now coincides with the deck plane) is shown, as well as the gun elevation above the deck plane, $E'g$. Here $E'g$ equals the gun elevation above the horizontal (Eg), only because the deck is horizontal.

Let's now see what happens to the gun position when the deck is tilted by Zh with Ds present. This is shown in figure 11–36. A study of the diagram will tell you that two important things happened to the gun position. First, the

Digitized by Google

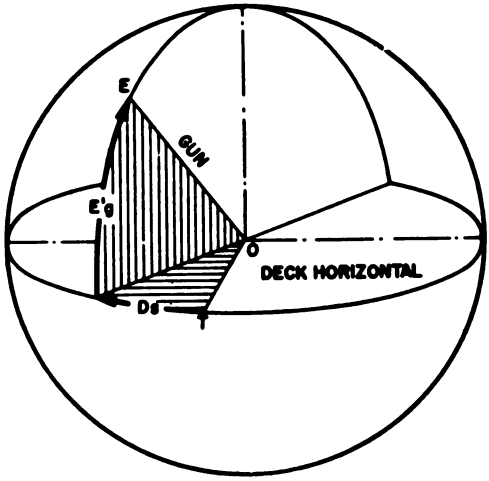


Figure 11–35.—Sight deflection causes no change in the position of the gun trunnions when the deck is horizontal.

bore axis of the gun has been deflected to the left and elevated from point E to E′. And second, the train of the gun in the deck plane remains essentially the same.

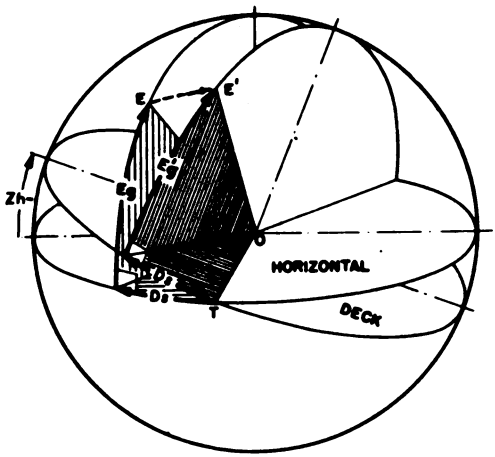


Figure 11–36.—Effect of cross level with sight deflection present.

Digitized by Google

Figure 11–37 shows the corrections necessary to bring the gun muzzle back to the computed point E. Again an elevation and a train correction are necessary. *Dz* takes care of the correction *a* in the slant plane, and *Vz* corrects the gun elevation. Notice that the *Dz* correction is about the same size as when there was zero deflection, but *Vz* is much larger because the gun is positioned farther uphill as a result of *Ds*.

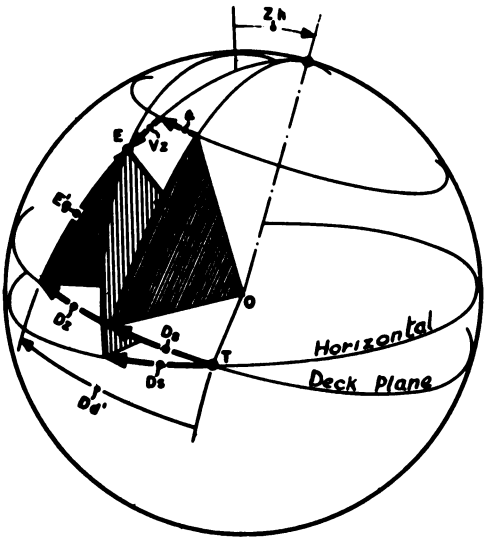


Figure 11–37.—Corrections for trunnion tilt with deflection present.

One new quantity is shown in figure 11–37. It is called DECK DEFLECTION *Dd'*. Deck deflection is the total amount the gun must be trained in the deck plane to correct for trunnion tilt plus all ballistics. Thus, since *Ds* contains the corrections for all ballistics, and *Dz* is the train correction for trunnion tilt, $Dd' = Ds + Dz$.

Effect of Level on Trunnion Tilt

You're probably wondering about the effect of level on trunnion tilt. The answer is quite simple. Its effect is so slight that it is neglected altogether. However, it is very important to understand that level elevates and depresses

Digitized by Google

the gun and must be allowed for. It is therefore added directly to Vz in calculating $E'g$. L' hardly affects Dd' and is sometimes ignored. It should be noted, however, that large values of L' will have the effect of making Dz slightly over-correct when Dz is large.

Putting the facts together, we find that the trunnion tilt corrections vary with both Vs and Ds, with the cross level angle, and, to a much smaller extent, with level. Thus, the trunnion tilt computer shown in figure 11–38 takes Vs, Ds, Zh, and L' as inputs to produce the trunnion tilt elevation correction (Vz) and the trunnion tilt train correction (Dz).

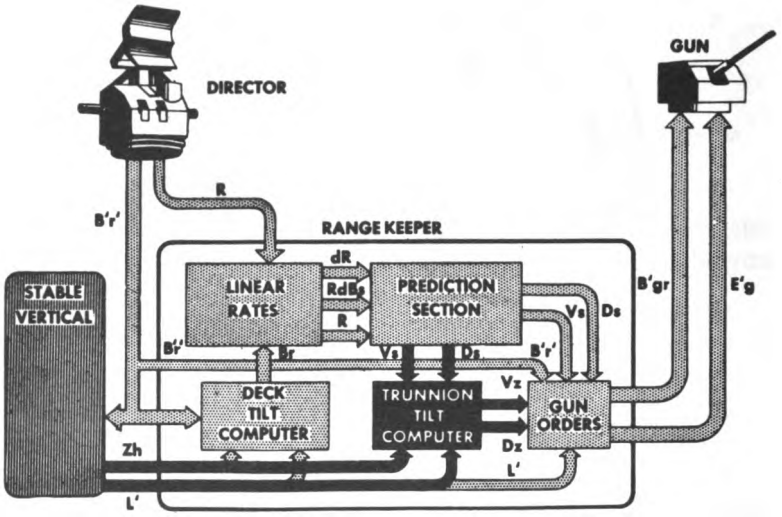


Figure 11–38.—Where the trunnion tilt computer fits in.

As shown in figure 11–38, Vz, Dz, Vs, Ds, and $B'r'$ are then fed to the gun order section of the rangekeeper to make up the gun elevation and gun train orders. You'll learn about the gun orders in the following chapter.

TRUNNION TILT COMPUTATIONS

Now that we know how the trunnion tilt computer fits in, let's take a look at the actual main battery mechanism shown

Digitized by Google

in figure 11–39. It mechanically solves for Dz and Vz with two computing-cam multipliers, three rack-type multipliers, various differentials, and a servo follow-up. The inputs Vs, Ds, L' and Zh are shown at the left, whereas the output Dz and Vz are shown at the right.

The trunnion tilt computer solves for Dz in the following equation:

$$Dz=[f(L')\ f_1(Vs)+KVs]\ [Zh+K_1L'Ds].$$

This formula shows that the calculation of Dz involves the multiplication of two main quantities.

The first quantity is computed by the special double-cam computing multiplier shown in the upper left hand corner of figure 11–39, and the differential D-1.

The second quantity is computed by the $L'Ds$ multiplier and the differential D-2 which are both shown in the lower central part of the figure.

The expressions $f(L')$ and $f_1(Vs)$ are functions of L' and Vs. These functions are computed by the grooves cut in the respective cams of the $f(L')f(Vs)$ computer. The follower slides are positioned in accordance with the follower pins which ride in the cam grooves. These slides position the output rack. The product of the two functions is thus represented as a shaft position.

The product $f(L')f_1(Vs)$ is now fed to differential D–1 where it is added to KVs to give

$$f(L')f_1(Vs)+KVs,$$

which becomes one input to the Dz multiplier. This completes the computation of the first quantity of Dz.

The second main quantity of Dz is composed of the sum of $K_1L'Ds$ and Zh. The $L'Ds$ multiplier produces $K_1L'Ds$ from the Ds and L' inputs. K_1 is a constant which can be taken care of in a gear ratio. Zh is then added to $K_1L'Ds$ in differential D–2, whose output is fed to the Dz multiplier. This completes the computation of the second quantity of Dz.

The two main quantities, represented at the D–1 and D–2 outputs, are now multiplied in the Dz multiplier of figure

Digitized by Google

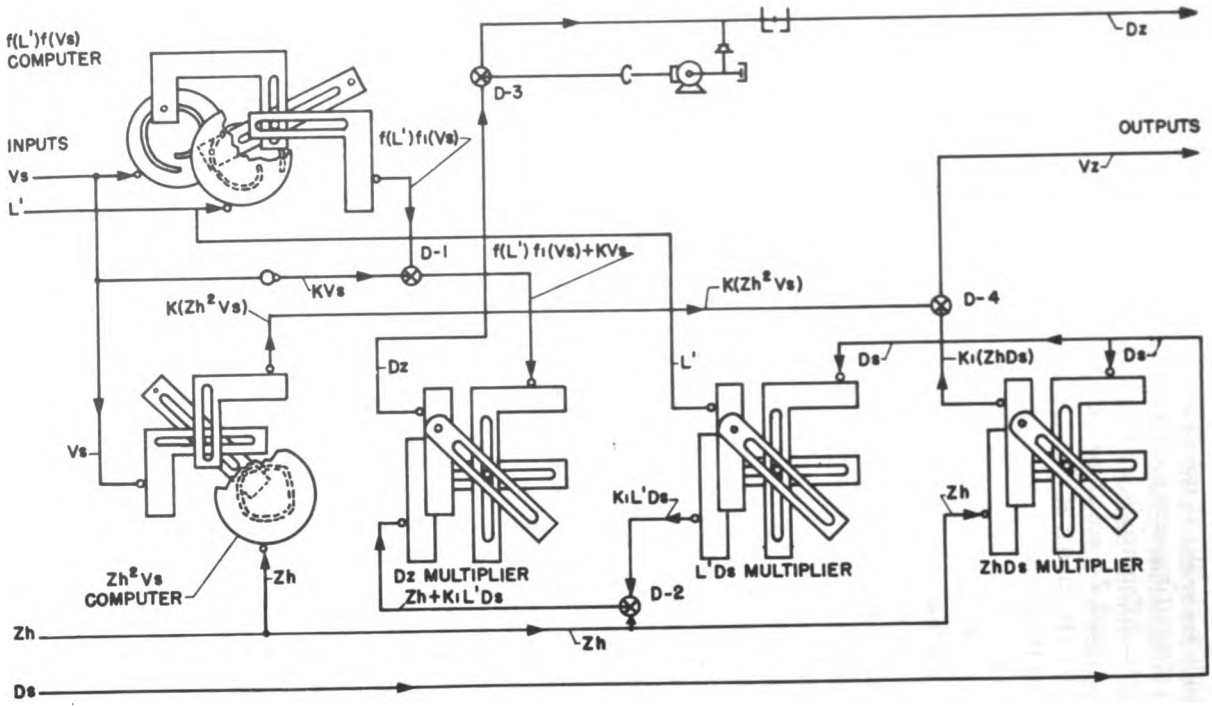


Figure 11–39.—Typical trunnion tilt computer.

Digitized by Google

11–39. Dz is then sent to the D–3 differential of the servo follow-up, where it is amplified.

The trunnion tilt computer of figure 11–39 has the additional task of solving for the elevation trunnion tilt correction, Vz, from the following formula:

$$-Vz = K(Zh^2Vs) + K_1(ZhDs).$$

You'll remember from our previous discussion that Vs is always a down, or negative, correction. That's the reason for the minus sign.

This equation is easily worked with the square-cam computing multiplier in the lower left corner, and the lower right hand multiplier, both of figure 11–39.

Zh and Vs are the inputs to the Zh^2Vs computer. Zh is squared by the cam whose output helps position the multiplier output slide. The other input Vs positions the multiplier input slide, which also aids in positioning the multiplier output slide. Thus, the product of Zh^2 and Vs is represented by the position of the output slide. The constant K is taken care of in the construction of the square cam.

The outputs of the Zh^2Vs computer and the $ZhDs$ multiplier are added by D–4 to give Vz. This completes the calculation of the trunnion tilt corrections.

DECK TILT COMPUTATIONS

Back when you studied figures 11–21, 11–22, and 11–23, you found out what the deck tilt correction $jB'r'$ is, and how it was used. We'll go a little further at this point and see how the deck tilt computer solves the $jB'r'$ equation from the following formula:

$$jB'r' = K[\tfrac{1}{2}(L'^2 - Zh^2) \sin 2B'r' - ZhL'(1 + \cos 2B'r')].$$

It looks fairly complex, but if you simply use it without worrying about its derivation you'll have no trouble.

Looking at the formula, we find the subtraction of two main quantities inside the brackets. This difference is then multiplied by the constant K.

Digitized by Google

Let's examine the first quantity inside the brackets. The ½ is taken care of with a gear ratio, so we'll neglect it. Also, $2B'r'$ is obtained by multiplying director train $B'r'$ in another gear ratio, so we'll not worry about it either. However, the L'^2-Zh^2 expression does require additional explanation in order to understand the operation of the deck tilt computer.

If you multiply $(L'+Zh)$ by $(L'-Zh)$ you get

$$L'^2+ZhL'-L'Zh-Zh^2=L'^2-Zh^2.$$

Thus, $(L'-Zh)$ and $(L'+Zh)$ are factors of L'^2-Zh^2.

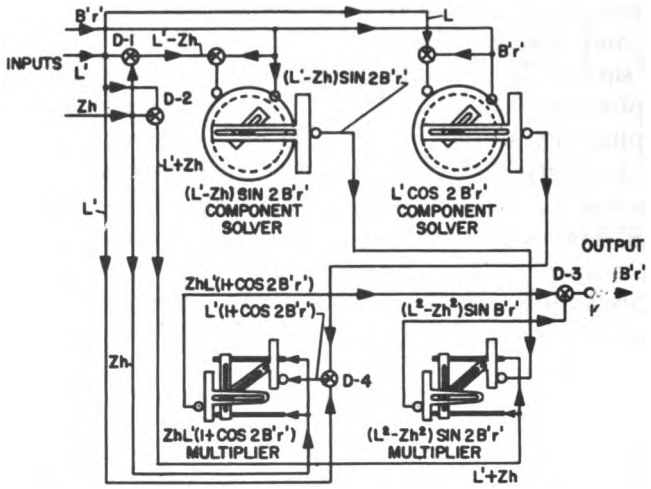


Figure 11–40.—Deck tilt computer.

An inspection of the schematic diagram of the deck tilt computer in figure 11–40 will show how these two factors are used. The $(L'-Zh)$ and $(L'+Zh)$ factors are obtained by subtracting and adding L' and Zh in the two differentials D-1 and D-2. Then the upper left component solver takes $B'r'$ and $(L'-Zh)$ as inputs to give $(L'-Zh)$ sin $2B'r'$. Remember, $2B'r'$ is obtained by multiplying $B'r'$ by 2 in a gear ratio. The upper left component solver output is then mul-

Digitized by Google

tiplied by $(L'+Zh)$ in the lower right multiplier to give (L^2-Zh^2) sin $2B'r'$. The ½ is taken care of in the gear ratio between the spider and side gears of D-3 to give ½ (L^2-Zh^2) sin $2B'r'$.

The second quantity in our $jB'r'$ equation is even more simple to solve. L' is resolved in the upper right component solver to give L cos $2B'r'$. This is now added to L' in the D-4 differential to give the sum

$$L'+L' \cos 2B'r'$$

which, by factoring out L', gives

$$L' (1+\cos 2B'r').$$

Next, this expression is multiplied by Zh in the lower left multiplier to give $ZhL' (1+\cos 2B'r')$.

Finally, $ZhL' (1+\cos 2B'r)$ is subtracted from ½ (L'^2-Zh^2) sin $2B'r'$ in the differential D-3. (Note: ½ is taken care of in D-3 and therefore is not shown on the print.) When this sum is multiplied by K in the gear ratio at the output side of D-3 we have our final answer $jB'r'$, the deck tilt correction.

Summing up, it should be recalled that $jB'r'$ is added to director train $B'r'$ to give Br, the relative target bearing in the true horizontal plane. Br then enters into the solution of the own ship and target motion problem, which has already been discussed.

QUIZ

From the following select the answer (*a*, *b*, *c*, or *d*) which best completes the statement or answers the question.

1. Br is equal to director train only when
   - (*a*) range is constant.
   - (*b*) the deck is level.
   - (*c*) L' is at a positive value.
   - (*d*) Zh is present.
2. Deck tilt is measured with respect to the
   - (*a*) line of sight.
   - (*b*) ship's centerline.
   - (*c*) level axis.
   - (*d*) cross-level axis.

Digitized by Google

3. Relative target bearing is equal to the sum of
   (*a*) *Zh* and *B'r'*.
   (*b*) *L'*, *Zh*, and *B'r'*.
   (*c*) *Dz* and *B'r'*.
   (*d*) *B'r'* and *jB'r'*

4. Which one of the following inputs must the stable vertical have to measure level and cross-level with respect to the LOS?
   (*a*) *jB'r'*.
   (*b*) *R*.
   (*c*) *Br*.
   (*d*) *B'r'*.

5. When the level and cross-level follow-up motors reposition the umbrella over the magnet, the signals to the motors become zero when
   (*a*) the level gimbal is level.
   (*b*) the cross-level gimbal is level.
   (*c*) both the level and cross-level gimbals are level.
   (*d*) the supporting fork is positioned through the *B'r'* angle.

6. The follow-up motors in the stable vertical reposition the umbrella, and also
   (*a*) drive the same amount into the rangekeeper.
   (*b*) correct for director train.
   (*c*) correct for director elevation.
   (*d*) drive the gyro by the same amount.

7. When measured at the director, *L'* and *Zh* are measured
   (*a*) in and across the LOS.
   (*b*) with respect to the ship's centerline.
   (*c*) by the pointer and trainer.
   (d) by an auxiliary mechanism.

8. When *Zh* is plus and no sight deflection is present, the elevation correction for trunnion tilt (*Vz*) is
   (*a*) positive.
   (*b*) negative.
   (*c*) up.
   (*d*) zero.

9. When *Zh* is minus and no sight deflection is present, the elevation correction for trunnion tilt (*Vz*) is
   (*a*) positive.
   (*b*) negative.
   (*c*) up.
   (*d*) zero.

Digitized by Google

10. The trunnion tilt train correction (Dz) is measured in the
    (*a*) slant plane.
    (*b*) horizontal plane.
    (*c*) vertical plane.
    (*d*) deck plane.

11. Both Vz and Dz
    (*a*) increase as Vs increases.
    (*b*) decrease as Vs increases.
    (*c*) are independent of Vs.
    (*d*) are contained in Vs.

12. Vz and Dz are computed from the following inputs:
    (*a*) Vs, Ds, and L'.
    (*b*) Ds, Br', and Zh.
    (*c*) Vs, Ds, L', and Zh.
    (*d*) $E'b'$, Ds, $B'r'$, Vs, L', and Zh.

13. In the trunnion tilt computer the functions $f(L')$ and $f_1(Vs)$ are
    (*a*) cam outputs.
    (*b*) multiplier constants.
    (*c*) servo quantities.
    (*d*) differential outputs.

14. Which one of the following quantities is not an input to the trunnion tilt computer?
    (*a*) Vs.
    (*b*) Ds.
    (*c*) $B'r'$
    (*d*) L'.
    (*e*) Zh.

15. The Zh^2 Vs computer of the trunnion tilt mechanism is actually a
    (*a*) rack-type multiplier.
    (*b*) double-cam computing multiplier.
    (*c*) converted component solver.
    (*d*) single-cam computing multiplier.

16. From the $jB'r'$ formula, $L'+L'\cos 2\ B'r'$ is the input to a
    (*a*) differential.
    (*b*) multiplier.
    (*c*) component solver.
    (*d*) gear ratio.

Digitized by Google

Digitized by Google

CHAPTER 12

THE GUN ORDERS

This chapter will give you an over-all picture of a surface fire control system such as that used to control the main battery of a modern vessel. In the study of fire control, it is easy to overemphasize the function of certain equipment such as the rangekeeper, without fully appreciating how that equipment fits into the complete system.

Every fire control system used for the control of the main battery is comprised of a group of instruments working together to produce gun train order $B'gr$ and gun elevation order $E'g$, both of which position the gun to hit the target. The system you have studied thus far consists of four major units: the director, the rangekeeper, the stable vertical, and the guns.

You are now ready to discuss how these elements work together. However, to bring you up to date, a short discussion of the information that flows into the gun orders will first be discussed.

In the study of a fire control system and in the location of an error which might be present in the system, there are three basic elements of gun orders which you must thoroughly understand. These quantities are the angles which are added together to produce the gun orders. These angles can be classified into three groups as indicated in figure 12–1.

The first step (upper block in figure 12–1) is accomplished by the director. It measures the present target position

Digitized by Google

relative to the deck plane of the ship by its angle of train (director train $B'r'$) from the ship's center line as shown in figure 12–2. As you already know, the LOS from own ship to target is the baseline for all calculations performed by the rangekeeper and stable vertical. Therefore, $B'r'$ is transmitted to the stable vertical and the rangekeeper to establish the LOS.

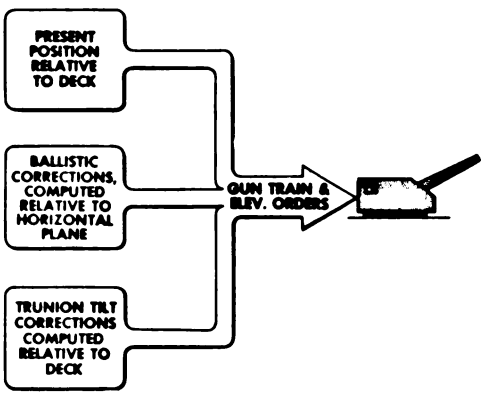

PRESENT POSITION RELATIVE TO DECK
BALLISTIC CORRECTIONS, COMPUTED RELATIVE TO HORIZONTAL PLANE
TRUNION TILT CORRECTIONS COMPUTED RELATIVE TO DECK
GUN TRAIN & ELEV. ORDERS

Figure 12–1.—Basic elements of gun train and elevation orders.

Another angle, director elevation $E'b'$, is also measured by the director in a plane perpendicular to the deck plane, through the LOS. However, $E'b$ is not always measured by the director. As you know, the stable vertical takes care of $E'b$ with the measurement of L'. Those main battery directors that measure $E'b$ can measure L' in the case of stable vertical failure. L' is contained in the angle $E'b$, and is measured by the director pointer as he keeps the director sight on the target.

The final measurement needed by the director to completely establish the target's present position relative to own ship is range, which is measured either by rangefinder or radar.

The second step in computing the gun orders is the calculation of the ballistic corrections, which are computed relative to the horizontal plane. (See fig. 12–1.) The

Digitized by Google

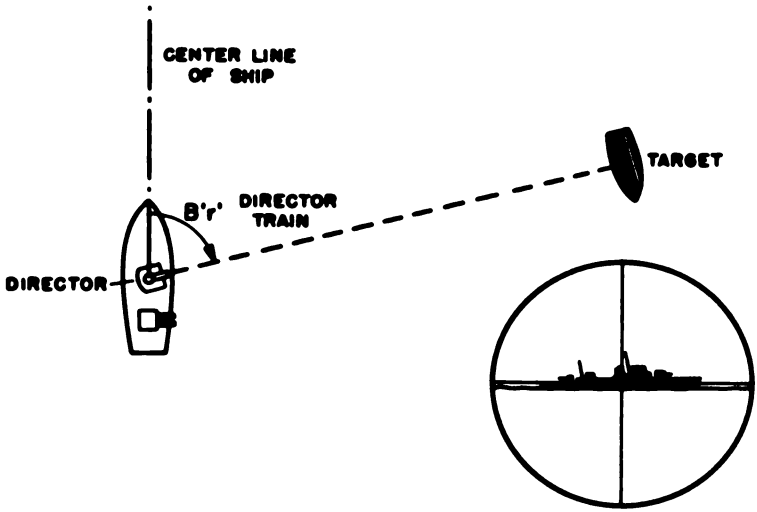


Figure 12–2.—Present target position is measured by director train.

stable vertical establishes the horizontal plane with its level and cross-level outputs. The quantity $B'r'$ is converted to Br in the deck-tilt section of the rangekeeper, by the quantity $jB'r'$ (deck-tilt correction). You'll recall that $jB'r'$ is made up in the rangekeeper from the director and stable vertical inputs ($B'r'$, $\bar{L}'$, and Zh).

Once the horizontal plane is established with Br, computations for own ship and target motion, wind corrections, drift, *I. V.* loss, and on through Vs and Ds, are solved to complete the second step.

The third and last step is the calculation of trunnion-tilt corrections relative to the deck (bottom block in figure 12–1), which is accomplished by the rangekeeper with the aid of the stable vertical. Also feeding into the gun orders is the quantity, L', one of the stable vertical outputs. It adds in to make up $E'g$.

Now, if you put all this information together, you have the gun orders. Let's discuss each gun order separately, commencing with the gun train order, $B'gr$.

Digitized by Google

GUN TRAIN ORDER

Gun train order is the result of an addition of three basic angular quantities already familiar to you—Dz, Ds, and $B'r'$. As shown in figure 12–3, gun train order is equal to

$$B'gr = Ds + Dz + B'r',$$

or, since Ds and Dz are added in the rangekeeper to give deck deflection, $D'd$, you can write

$$B'gr \quad D'd + B'r'.$$

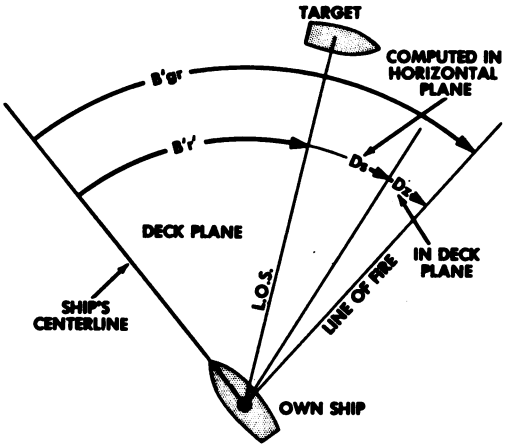


Figure 12–3.—Gun train order.

Of course, when the deck is level, $B'gr$ is equal to the sum of Ds and $B'r'$ because no trunnion tilt is present and Dz is zero.

As indicated in figure 12–3, gun train order positions the gun to the line of fire. You will recall that the line of fire lies in a plane, drawn through the bore axis of the gun, perpendicular to the deck of the ship.

You can see how the quantities manufactured in the rangekeeper and director are combined to produce $B'gr$ in figure 12–4. Ds and Dz are added in one differential to give $D'd$,

Digitized by Google

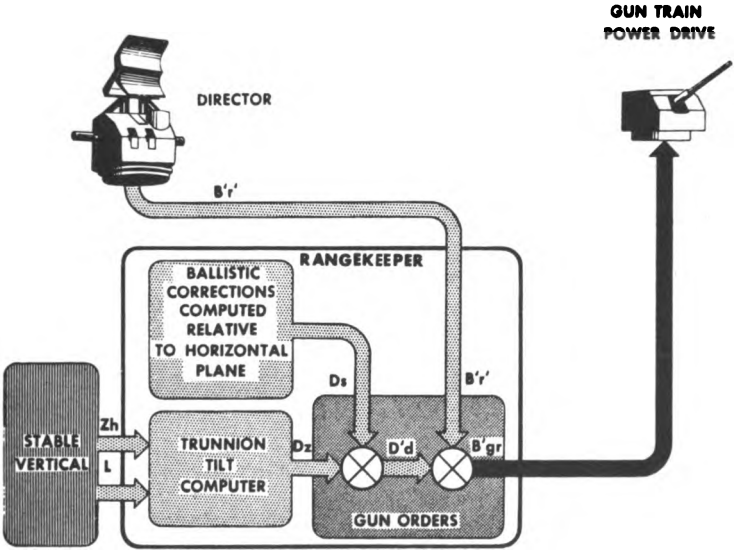


Figure 12–4.—How the rangekeeper manufactures B'gr.

and $B'r'$ and $D'd$ are added in another differential to give $B'gr$. $B'gr$ is then transmitted by synchro transmitters to the gun to control the power drive. Then the power drive trains the gun in response to the transmitted signal.

As you know, these power drives may consist of hydraulic or electric mechanisms and motors, or a combination of both.

Horizontal Parallax

It would be simpler to get gun train order if it were physically possible to mount the gun and director on exactly the same point on board ship. Normally, however, the director and gun are separated by a horizontal distance, which means their lines of sight will not be the same. This separation between director and gun makes a difference in determining the direction of the target relative to the line of fire. This brings up the term HORIZONTAL PARALLAX.

Digitized by Google

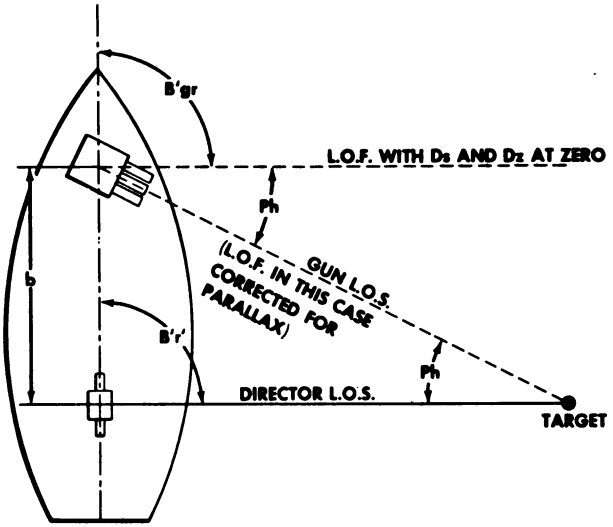


Figure 12–5.—Horizontal parallax with target abeam.

As shown in figure 12–5 the effect of horizontal parallax is greatest when the target is directly abeam. In this case assume that the ballistics are such that sight deflection is zero, and that the deck- and trunnion-tilt corrections are zero. Then, since $B'gr = B'r' + Ds + Dz$, gun train order would equal $B'r'$ because $B'gr = B'r' + 0 + 0$.

But, if the gun were trained through the angle $B'gr$, the projectile would not hit the target, as indicated in figure 12–5. Therefore, to score a hit, the gun must be trained around farther, through the horizontal parallax angle, Ph.

You can think of the parallax angle in two ways. It's the angle at the gun between the gun LOS and a line running through the gun, parallel to the director LOS. Also, it's the angle at the target between the gun and director LOS. It's clear from figure 12–5 that these two angles are the equal.

It should be clear from figure 12–5 that the value of Ph in mils is the base length, b, in yards, divided by the range in thousands of yards. That is $Ph = \frac{b}{R}$ mils. If you compare

Digitized by Google

this formula with the one you used for converting linear deflection to mils, it'll be easy.

This simple formula holds good only when the target is directly abeam. It should be obvious that Ph will be zero for a target directly ahead or astern.

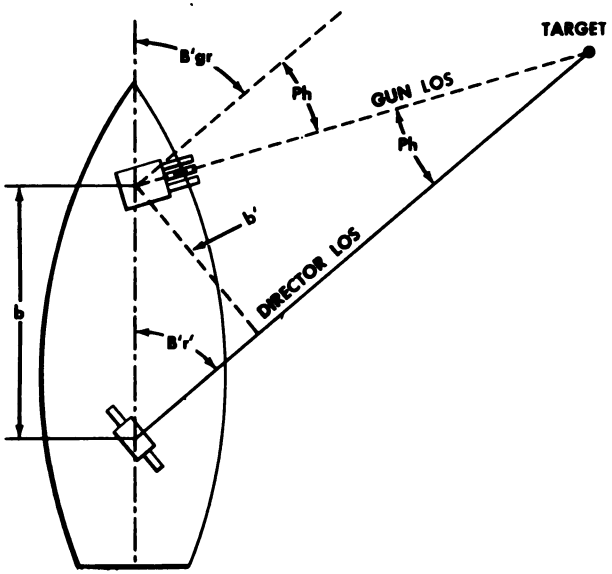


Figure 12–6.—How horizontal parallax is calculated for any train angle.

Figure 12–6 shows parallax for a target between these two positions. Here the angle is:

$$Ph = \frac{b'}{R}. \tag{1}$$

But it is more convenient to use b, so you compute it from the triangle formed by b, b', and $B'r'$:

$$b' = b \sin B'r' \tag{2}$$

$$\text{or, } b' = b \sin B'gr. \tag{3}$$

The use of $B'r'$ or $B'gr$ depends upon whether the computation is being performed at the director or the gun.

Digitized by Google

The parallax equation can now be solved by substituting the value of b' of (3) in (1), which gives

$$Ph = \frac{b \sin B'gr}{R}$$

$$\text{or, } Ph = b \sin B'gr \frac{1}{R}$$

where R in the equation may be either generated present range cR or advance range $R2$ depending upon the system.

If all guns were the same distance from the director, the parallax angle could be computed in the plotting room and included in gun train order. But since they are not, the correction for parallax is computed separately at each gun.

In most surface fire systems, inverse present range $\frac{1}{R}$ is transmitted to the guns from the rangekeeper in plot by synchro, and the rest of the computation is performed in a PARALLAX CORRECTOR at the gun.

The parallax corrector is nothing more than a component solver. Inverse range (the reciprocal of range), sometimes called parallax range, is received at the turret by synchro and becomes the speed input of the component solver. $B'gr$ is the angle input to the component solver (see fig. 12–7). b is assumed to be equal to 100 yards and is built right into the gearing of the inverse range input. Thus the component solver output is parallax based upon a 100 yard base. A set of change gears converts this value of parallax to the value required by the gun at which the parallax corrector is located. The change gears are located in the parallax corrector output shafting. These gears are ordinary gears which may be exchanged with ones whose ratio has been chosen to take care of the difference in base length compared to 100 yards. For example, if the gun is located 50 yards away from the reference point a 50/100 ratio is formed, and a 1:2 ratio set of gears is required.

The output (Ph) is combined in a differential with gun

Digitized by Google

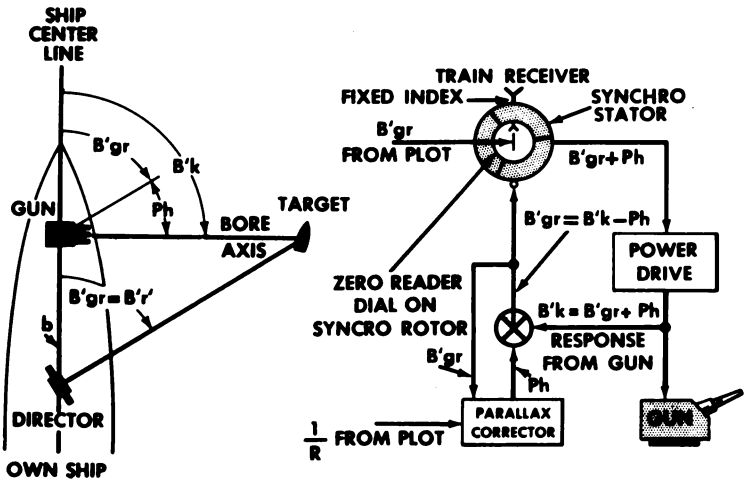


Figure 12–7.—Compensating for horizontal parallax in surface fire.

train response, which, of course, causes the gun to train through the angle *B'gr* plus *Ph* (called *B'k*).

A schematic arrangement of a train receiver with facilities for correcting horizontal parallax is shown in figure 12–7. A careful study of the figure will indicate that *Ph* simply corrects the *B'gr* input to the gun-train power drive. It does this when the two quantities combine as they are fed into the response line leading to the synchro stator. *Ph* is then substracted from the gun train response (*B'k*) in the differential. The differential output then positions the synchro stator through the correct response angle. Thus the gun automatically follows the *B'gr* signal corrected for parallax.

Director Parallax

In figure 12–8, suppose the forward director is in control, and is transmitting *B'r'* to plot, where *Ds* and *Dz* are added to make up *B'gr*. The guns, training in accordance with the *B'gr* order, are corrected for horizontal parallax to the forward director.

But suppose the after director takes control. Now the

Digitized by Google

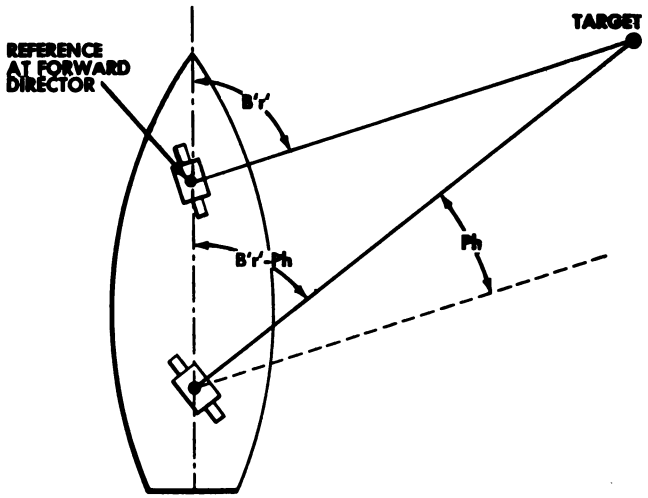


Figure 12–8.—Parallax between two directors.

train of this director is a smaller angle than train of the forward director. Thus, when the train of the after director is sent to plot the gun train order will be changed and the guns will move off the target. This happens because the guns are correcting for parallax with reference to the forward director, but are receiving gun train order based on the after director.

To remedy this difficulty, a parallax corrector is installed in the after director. This adds *Ph* to director train, which drives the director transmitters. Thus, the after director does not transmit actual director train; instead, it transmits the value which director train would have if the forward director were tracking the target.

In some installations, both directors have parallax correctors. Then each of them transmits to plot the value which director train would have if the director were located at some central REFERENCE POINT, as shown in figure 12–9. In other words, each director measures director train as if it were located at a common point.

When this is done, the horizontal base length set into each

Digitized by Google

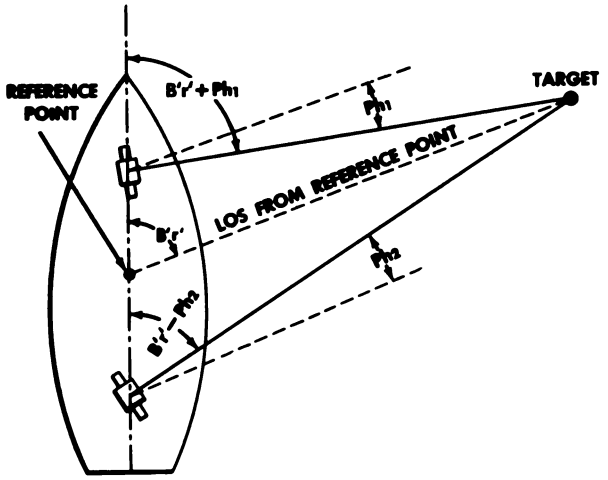


Figure 12–9.—Director horizontal parallax corrected to a central reference point.

director parallax-corrector is the distance the respective director is located from the reference point. From the foregoing it is evident that when all directors and guns are corrected for horizontal parallax with respect to some common reference point, any one director can control any gun or guns.

GUN ELEVATION ORDER

You can obtain gun elevation order $E'g$ by adding three basic angular quantities already familiar to you: they are

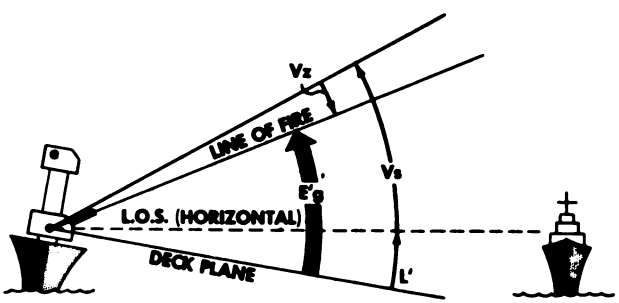


Figure 12–10.—Gun elevation order.

Digitized by Google

Vs, Vz, and L'. As shown in figure 12–10, gun elevation order is equal to

$$E'g = Vs + Vz + L'.$$

Actually, Vz, as you've learned when studying the trunnion-tilt section, is always a down or negative correction, so it is always subtracted from Vs and the difference is added to L'.

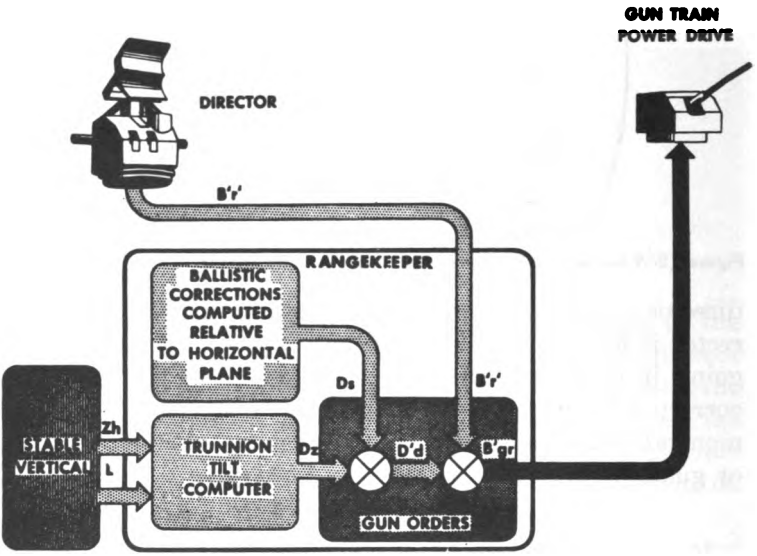


Figure 12–11.—How the rangekeeper manufactures E'g.

L' is transmitted directly from the stable element by shafting as indicated in figure 12–11. Vs, as you know, contains all ballistic corrections that are computed in relation to the horizontal plane. But since $E'g$ is measured from the deck plane, it is corrected for trunnion tilt by adding Vz to Vs in a differential. Then the sum of Vs and Vz is combined with L' in a second differential to make up the gun elevation order.

$E'g$ is now transmitted by synchro transmitters to the gun, where it is received by synchro receivers that control

Digitized by Google

the gun elevation power drive. This power drive elevates the gun in response to the $E'g$ signal in the same way that the train system performs its job.

Director Elevation and Vertical Parallax

When the surface system is in full automatic operation it is not necessary to use director elevation in the computation of the gun orders. Gun elevation order is computed entirely by the rangekeeper and stable vertical. Of course, present range, which comes from the director, is necessary in the computation of Vs. Then Vs enters into the solution of $E'g$.

But you will recall that, in the event of stable vertical failure, some other method of measuring L' must be available before $E'g$ can be computed. This is where the director comes in handy, for it takes care of L' at the same time it measures $E'b$. As you know, $E'b$ for surface fire is essentially equal to L'—in fact, it would be equal to L' if the gun and director were always located the same height from the deck. But this is not the case because the director is invariably located above the gun in order to improve visibility.

Consequently, vertical parallax, Pv, must be considered. Vertical parallax is caused by the vertical distance h between the director and gun (shown in fig. 12–12.) The

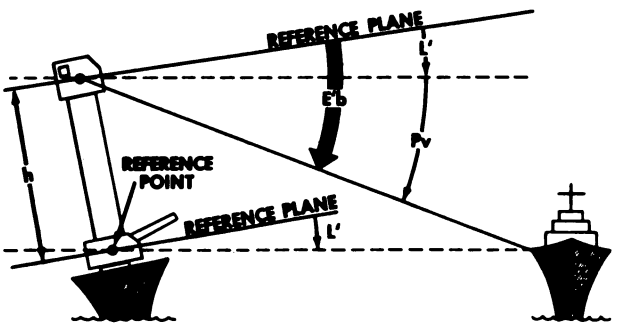


Figure 12–12.—Vertical parallax is taken into account when measuring L' at the director.

Digitized by Google

value of Pv is roughly equal to the vertical distance h multiplied by parallax range $\frac{1}{R}$. This multiplication of inverse range by the constant h is performed in a gear ratio at the director.

A hand crank and dial at the director pointer's station drives inverse range through a set of change gears into a differential in the line from the pointer's hand wheels to the level synchro transmitters as shown in figure 12–13. The dial is graduated backward so that it reads PRESENT RANGE, but actually, INVERSE RANGE is the quantity that is set in. Then the elevation of the gun LOS, or level, becomes the quantity that is transmitted to the rangekeeper in plot.

Reference Plane

The elevation of all elements of a battery is measured from a standard REFERENCE PLANE. This plane is arbitrarily selected for each ship; it may be the plane of the director roller path, or the roller path of a gun, as indicated in figure 12–12. The reference plane is especially important in battery alinement. It is approximately parallel to the deck plane, but some deviation will always exist.

The reference plane is absolutely necessary because no two elements in a battery have parallel roller paths. One unit may tilt astern, another to port, or still another to starboard. Of course, these roller paths only deviate from each other by a few minutes of tilt, but a few minutes may mean a miss at a range of several thousand yards. So a reference plane common to all battery elements is chosen, and then all elements are corrected to this reference.

Up to now you have learned that the stable vertical computes L' and Zh with respect to the horizontal. Well, that's only true to a point. Actually, the stable vertical is physically mounted so that it measures L' and Zh with respect to the reference plane. Thus, the reference plane is not neces-

Digitized by Google

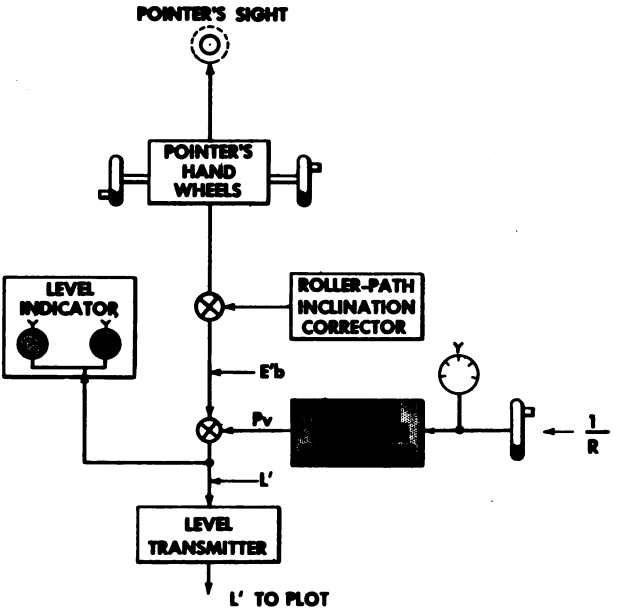


Figure 12–13.—Inverse range is cranked in at the director pointer's station.

sarily a true horizontal, although we speak of it as such to make the discussion of general problems easier.

Each other element in the battery has a roller-path compensator as shown in the director of figure 12–13. The roller-path compensator is adjusted for each battery element to correct all transmitted elevation angles to the reference plane. Thus, as the director in figure 12–12 transmits level to the gun, its roller-path compensator (fig. 12–13) corrects level to the reference plane. Then, the gun takes this level angle and corrects it to its own roller path with a second roller-path compensator located right at the gun. Thus, the gun is always elevated above the deck by the correct angle $E'g$.

Reference Point

The reference point shown in figure 12–12 should not be confused with the reference plane. The reference point is

Digitized by Google

always chosen to represent the mean height of the gun trunnions, so that the vertical base h will be approximately right for correcting director elevation for vertical parallax. Of course, when Pv is subtracted from $E'b$ you get L'—the angle the director would measure if it were moved down to the same level as the gun. Customarily, this is called referring director elevation to the mean gun, or reference point.

Be sure to understand that vertical parallax actually refers all elevation angles measured by the director to the reference point.

SYNCHRO TRANSMISSION

All information that flows into the gun orders is transmitted and received electrically by synchro transmitters and receivers.

Figure 12–14 is a simplified diagram of a main battery fire control system showing how quantities that help make up the gun orders are received by synchro from the director and stable vertical, and how the rangekeeper outputs—the gun train and elevation orders—are transmitted by synchro. A thorough understanding of this setup will help you trouble-shoot in both main battery and dual-purpose fire control systems because they are essentially laid out the same.

Let's trace through figure 12–14 as a final step in learning how the gun orders are made up. Taking gun train order first, the most important thing to remember is the formula, $B'gr = B'r' + Dz + Ds$. You know that $B'r'$ is director train, so the logical place to start is at the director. Look at the print and trace $B'r'$ from the director to the synchro receiver at the rangekeeper. The $B'r'$ receiver converts the electrical signal to a shaft position, which is amplified in torque by a servo follow-up motor (for simplicity the servo motors are not shown in figure 12–14), and is then fed to the ouptput differential.

At the same time, the deflection ballistic corrections are being solved by the rangekeeper to make up Ds which also appears as a shaft position. This Ds shaft position is ampli-

Digitized by Google

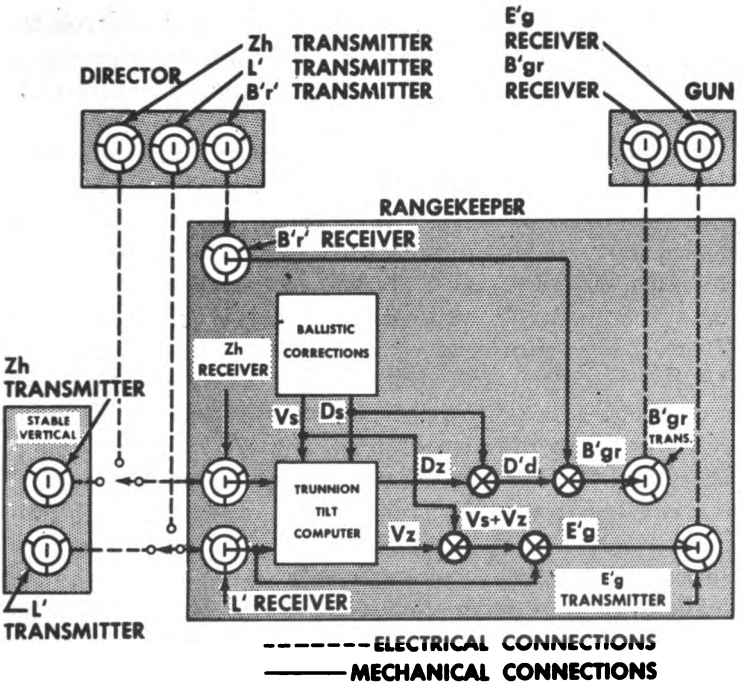


Figure 12–14.—Quantities that make up the gun elevation and train orders are transmitted and received by the synchro.

fied by another servo motor before being added to *Dz* in a differential.

Dz, the trunnion-tilt train correction, is computed in the trunnion-tilt computer from *Vs* and *Ds* (which are received mechanically from the ballistic correction section), and from *L'* and *Zh* (which are received electrically from the stable vertical). *Dz* is then amplified by a third servo motor before being added to *Ds* to make *D'd*.

Finally, *D'd* is added to *B'r'* in the output differential to make up *B'gr*—a shaft position. The *B'gr* shaft positions the rotors of a set of fine and coarse synchro transmitters (only one is shown in figure 12–14 although two are used). These transmitters transmit *B'gr* to the gun receivers, which

Digitized by Google

are a part of the train receiver regulator which controls the power drive. The power drive builds up the $B'gr$ signal with sufficient power to drive the gun mount (or turret) in train.

Gun elevation order is made up in much the same way. Here again, knowing the formula for elevation order, $E'g = Vs + Vz + L'$, is the first essential. Vz is made up in the trunnion-tilt computer from Vs and Ds which come from the ballistic section, and L' and Zh received by synchro which come from the stable vertical or director. Of course, both the L' and Zh synchro receiver outputs are amplified by servo follow-up motors before being used in the rangekeeper. Vz is then added to Vs by a differential, and their sum is added to L' by another differential to make up $E'g$. The $E'g$ shaft position is then converted to an electrical signal in a set of fine and coarse synchro transmitters and sent to the gun. $E'g$ controls the elevation power drive the same way as $B'gr$ controls the gun train order power drive.

Thus, the guns automatically train and elevate to the line of fire in accordance with the rangekeeper outputs.

QUIZ

From the following select the answer (*a*, *b*, *c* or *d*) which BEST completes the statement or answers the question.

1. The angle measured by a director (surface) from the bow of own ship to the LOS is
   (*a*) $B'r'$.
   (*b*) Br.
   (*c*) B.
   (*d*) $B'gr$.

2. In a main battery surface system, director elevation is measured in order to determine
   (*a*) Zh.
   (*b*) L'.
   (*c*) Eg.
   (*d*) E.

Digitized by Google

3. In surface fire, the two director quantities required to establish target present position are

   (*a*) director elevation and the line of sight.
   (*b*) director train and director elevation.
   (*c*) director elevation and range.
   (*d*) director train and range.

4. One time that you use director elevation in surface fire is when
   (*a*) accuracy is important.
   (*b*) the stable vertical fails.
   (*c*) level is not required in the gun orders.
   (*d*) trunnion-tilt corrections are unnecessary.

5. Gun train order is equal to the sum of
   (*a*) *B'gr*, *Ds*, and *Dz*.
   (*b*) *Ds*, *Dz*, and *L'*.
   (*c*) *B'r'*, *Ds*, and *Dz*.
   (*d*) *Br*, *Ds*, and *Dz*.

6. The only time horizontal parallax correction is not necessary between director and gun, separated by some horizontal distance, is when the target is
   (*a*) ahead or astern.
   (*b*) at ranges beyond 10,000 yards.
   (*c*) headed directly toward own ship.
   (*d*) directly abeam.

7. Horizontal parallax varies with
   (*a*) own ship speed.
   (*b*) target speed.
   (*c*) target angle.
   (*d*) range.

8. Horizontal parallax is computed with a component solver at each gun, which solves the following formula:
   (*a*) $Ph = b' \cos B'gr \frac{1}{R}$.
   (*b*) $Ph = \frac{b}{R} \sin B'gr$.
   (*c*) $Ph = b \sin B'gr$.
   (*b*) $Ph = b \cos B'gr$.

9. Why is it necessary to correct at least one director for horizontal parallax in a two-director installation?
   (*a*) So that all guns and directors can be alined to the same point.

Digitized by Google

(*b*) To eliminate the necessity for correcting parallax at the guns.

(*c*) To simplify battery alinement at sea.

(*d*) To measure the horizontal base length for transmission to the gun parallax corrector.

10. In a surface fire control system, the only quantity transmitted from the rangekeeper to the parallax correctors at the guns is

(*a*) b.

(*b*) Ph.

(*c*) $\frac{b}{R}$.

(*d*) $\frac{1}{R}$.

11. When two directors, separated by a certain horizontal base length, are corrected for horizontal parallax, their

(*a*) transmitted director train angles are equal.

(*b*) train angles from the bow of the ship to their lines of sight are equal.

(*c*) present range outputs will be corrected to a fixed point.

(*d*) train angles will be equal only when the target is directly abeam.

12. Gun elevation order is equal to the sum of

(*a*) Zh, L', Vs, and Vz.

(*b*) Vs, Vz, and L'.

(*c*) $f(L')$, Vs, and Dz.

(*d*) Zh, Vs, and Vz.

13. Director elevation minus vertical parallax, Pv, is substantially equal to

(*a*) E'.

(*b*) E.

(*c*) L'.

(*d*) $\frac{h}{R}$.

14. All guns are alined in elevation to the

(*a*) reference plane.

(*b*) reference point.

(*c*) deck plane.

(*d*) mean trunnion height.

Digitized by Google

15. Vertical parallax corrects director elevation—which is essentially L' after correction—to the
    (*a*) rangekeeper base.
    (*b*) horizontal plane.
    (*c*) reference plane.
    (*d*) reference point.

Digitized by Google

Digitized by Google

CHAPTER 13

GENERATED RATES

EFFECT OF TARGET MOTION ON RANGE

All rangekeeper computations discussed earlier were based on values which were cranked into the machine. We had to assume that those initial values were correct to solve the problem. For example, you used present range R in all computations. But a little reasoning will tell you that R changes as the target and own ship change their positions. Not only will R change, but range rate dR will also change as target angle A and relative target bearing Br change. The rangekeeper operator would have to continually crank in R manually in order to get a good solution. To do that, he would have to be told what present range is from instant to instant. This would be a cumbersome way of keeping range.

However, the rangekeeper is designed to keep range for you. It generates a quantity known as GENERATED PRESENT RANGE cR (c being the symbol for generated). In all range keeper calculations, cR takes the place of R, and it is computed with the help of an integrator. On the rangekeeper instrument panel, cR appears as a counter reading. The rangekeeper operator simply watches the counter and compares generated and observed range (cR and R), and makes corrections to the initial setting of range whenever necessary. (See fig. 13–1.)

Digitized by Google

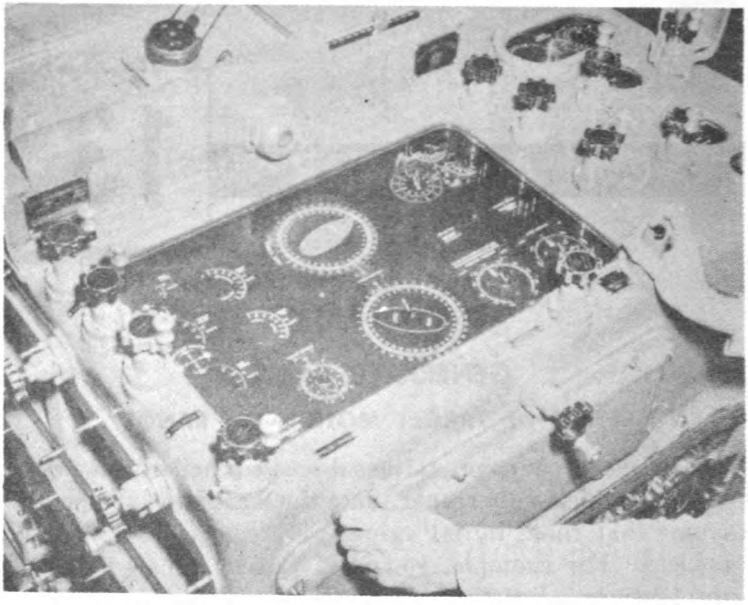


Figure 13–1.—Rangekeeper operator correcting range.

Let's first investigate what happens to range as the target moves, before tackling the problem of generating $\dot{c}R$.

Suppose the range is known at some instant. The course and speed of own ship are known. You can estimate target angle and speed. Then it is obviously possible to calculate what the range should be at any later time.

Once in a while you can compare this calculated range with a measured value. If it turns out to be wrong, you know that your estimates of target motion were wrong. So you adjust your estimates and try again.

Suppose that in figure 13–2, own ship is at rest and the target ship is in position B moving at speed S. Its direction is at right angles to the LOS. That is, target angle equals 90°. If you resolved S into components across and along the LOS, the range component would be zero and deflection component would equal target speed S.

Digitized by Google

When the ship is in this position the range is not changing at all. Target movement is changing the bearing of the target, but, for the moment, range is not changing. Of course, if the target moved a short distance along its course, target angle would begin to increase, the range component of *S* would be greater than zero—as in position *C*—and range would begin to increase.

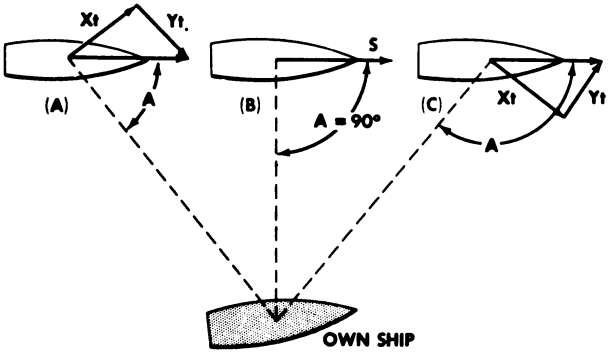


Figure 13–2.—Effect of target movement on range.

You can see that the speed with which range is changing, range rate *dR*, depends upon the value of the range component of target movement. Thus, at position *A* in figure 13–2, target angle is less than 90°, the range component is tending to close the range, and the range is decreasing at a speed equal to the target range component *Yt*. At position *B*, where *A* equals 90°, there is no range component, and the range is not changing. A little later at position *C*, the target angle is greater than 90°, *Yt* points outward, and the range is increasing.

The same reasoning applies to the movement of own ship. You can see in figure 13–3 that the rate at which range changes will depend on *Yt* and *Yo*. As you learned previously, the sum of *Yt* and *Yo* is equal to range rate *dR*, where *d* is a sign meaning "rate of change of." You have $dR = Yt + Yo$.

Remember that this is purely an instantaneous value, and

Digitized by Google

is true only for a given instant because dR changes as target angle and relative target bearing change.

However, as long as Br and A are correct, even though they are always changing, the own ship and target component solvers will always furnish the correct value of dR. And dR will always indicate the speed with which range is changing at any instant.

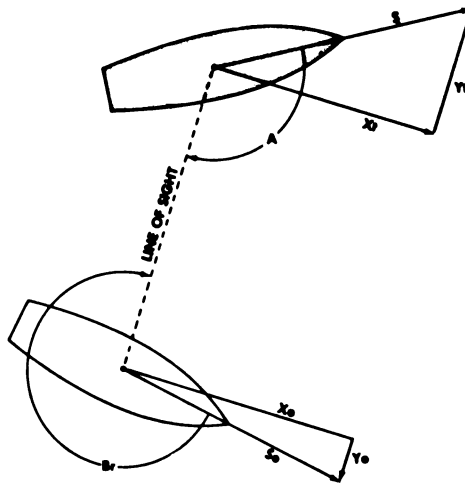


Figure 13–3.—How range rate is obtained.

Therefore, in order to get the total change in range over a given period of time, all you have to do is INTEGRATE dR. That is, you multiply dR by time as time elapses. The result will be the total change in range in yards at the end of any given period of time. The integrator performs this function continuously.

THE RANGE INTEGRATOR

Examining the process of integration a little closer, assume that dR is equal to 20 yards/second. After 10 seconds the total change in range would be 200 yards—that is, change in range equals dR times time, or $20 \times 10 = 200$ yards. But this is not a typical case because dR is always changing.

Digitized by Google

A better example is shown when several values of *dR* are taken over a given period of time. Say that for the first 5 seconds *dR* is 20 yards/second, for the second 5 seconds *dR* is 25 yards/second, and for a third 5 seconds *dR* is 30 yards/second. Then at the end of 15 seconds the total change in range would be the sum of the products of all three *dR's* multiplied by the times over which each persists, or 375 yards:

$$dR1 \times T1 = 20 \times 5 = 100 \text{ yds.}$$
$$dR2 \times T2 = 25 \times 5 = 125 \text{ yds.}$$
$$dR3 \times T3 = 30 \times 5 = 150 \text{ yds.}$$

Total change in range = 375 yds. (total).

This is essentially the process of integration.

Now *dR* doesn't change in steps because neither target angle nor relative target bearing change in steps. Instead, *dR* changes smoothly. At one moment it may be gradually decreasing to zero, and at another it may be increasing. At any rate, it'll always change like a smooth curve on a graph.

Given the changing values of *dR*, the range integrator is free to do its work. Using an infinite number of values of *dR*, the range integrator multiplies each value by the infinitesimal time over which it persists. Then it continuously adds or accumulates the products of these multiplications. The result is known as the INCREMENTS OF RANGE, or ΔcR. In this quantity the Greek letter delta, Δ, means either "changes in" or "increments of." Therefore, ΔcR will always give you the total change of range at the end of any given period of time.

The range integrator disk in figure 13–4 is driven at a constant speed by an electric motor known as the TIME MOTOR. The carriage is positioned by a rack and pinion, driven by the *dR* shaft. When the range rate is zero, the balls in the carriage are directly over the center of the disk as shown, and the disk rotation has no effect. However, if the range rate input has a definite value, the carriage and balls will be moved off toward one side of the rotating disk.

Digitized by Google

When this occurs, the motion of the disk will be transferred by the balls to the roller, and the roller will then revolve at a speed which depends on the displacement of the carriage from zero, and also upon the value of dR. The amount of roller rotation represents increments of range ΔcR.

The accuracy of ΔcR depends upon two things—dR and time. Naturally, dR depends on how accurate the settings are at the own ship and target component solvers. You know about dR already. Time is equally important, and therefore is introduced by a very special mechanism shown in figure 13–4.

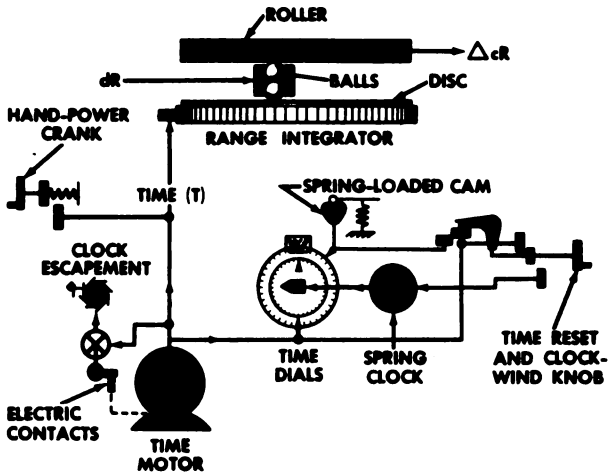


Figure 13–4.—Range rate integrator showing how time is introduced.

The time motor is an ordinary split-phase induction motor with a special regulator to make it run at an exact constant speed.

Here's how the time device works. One side of the differential is driven by the time motor, which always tries to run too fast. The other side of the differential is connected to an escapement movement like that in a clock. The important thing about an escapement is that it can be turned freely at a certain speed, but resists being turned any faster.

Digitized by Google

When the time motor is running at the escapement speed, it drives out of the differential through the escapement. But if the motor turns faster, the escapement resists, and the excess motion backs up into the differential spider. This opens the electric contacts shown in figure 13–4, cutting the power off the motor until it slows down to the proper speed. Of course, this happens very quickly from instant to instant and the rotation of the motor shaft appears perfectly constant. In this manner the time motor is always kept at the same constant speed.

The arrangement of the time dial in figure 13–4 is a little complicated. The time motor drives the inner dial at one turn per minute, and the outer dial at one turn per hour. The pointer is driven at one turn per minute by the spring clock. This provides a check on the accuracy of the time motor speed. The inner dial and the pointer should move together when the motor is running at the correct speed.

Also, if the time motor should fail, the hand power crank can be pushed in and used to drive time into the rangekeeper by hand. It should be turned at a rate which makes the minute dial move with the pointer.

When the time knob is pulled out from its neutral position, it is used to wind the spring clock. This must be done weekly. When the knob is pushed in, it disconnects the outer dial from the time motor, and a spring-loaded heart cam snaps the outer dial to zero. At the same time, the knob is geared to the time line and the inner dial can be set at any desired point.

Generated Present Range

With ΔcR being constantly generated, generated present range cR may be found by adding ΔcR to initial range jR. As you know, jR is measured by the rangefinder or radar. This addition is made in a differential as shown in figure 13–5. So you have

$$cR = jR + \Delta cR.$$

Digitized by Google

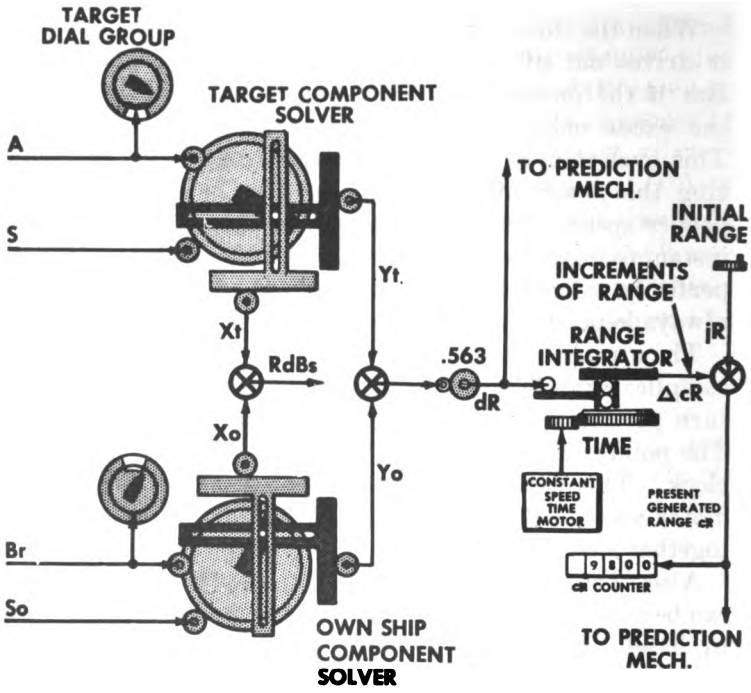


Figure 13–5.—Generated present range *cR*.

Notice that generated range is indicated on the counter. By observing the *cR* counter, the operator may make a comparison of the generated and observed values of present range.

If they don't agree, the operator uses rate control to correct the inputs of target angle and target speed. Of course, the initial setting of range, *jR*, could also be in error. But it is easy to tell whether the target inputs or *jR* is wrong. If *cR* "creeps" away from the observed range, then the target inputs are in error; if *cR* is always incorrect by a constant amount, *jR* is in error. If *jR* is in error, you simply crank the initial range knob until the *cR* counter reads the correct present range.

Digitized by Google

GENERATED BEARING

Suppose you're a director trainer and visibility is poor. One instant you have a clear view of the target through your telescope, and the next you can't see the target at all. Naturally, you will have trouble sending down correct values of $B'r'$ to the rangekeeper because you can adjust your handwheels only when the target is in sight.

But fire control machines make such a slow and unreliable procedure unnecessary. The rangekeeper is designed to generate true target bearing from the initial settings of own ship and target motion, and target bearing. Thus, if the target is momentarily obscured, the rangekeeper will maintain a correct target bearing in the absence of director train as long as the target maintains its same course and speed. Whenever the director trainer is on target, the rangekeeper operator compares the GENERATED and OBSERVED QUANTITIES just as he does when handling range.

Generated target bearing cB is generated with the assistance of two integrators. cB is obtained by computing INCREMENTS OF BEARING ΔcB by integration, and adding them to INITIAL BEARING jB. ΔcB indicates the TOTAL CHANGE in true bearing at the end of any period of time. Thus, at any instant, ΔcB plus jB will give cB. Then, if you subtract Co from cB, you will get the GENERATED RELATIVE TARGET BEARING, cBr.

Linear deflection rate $RdBs$ indicates how fast bearing is changing, so it is the key to solving for ΔcB. To arrive at the formula for ΔcB, you must first multiply $RdBs$ by time. This gives a linear distance in yards tangent to the present range circle. But, of course, what you want is the change in the bearing angle in minutes. So it is necessary to divide by $\frac{cR}{1000}$, thus changing the linear distance to mils. Then, to get minutes you multiply by 3.43 (or more exactly, by 3.438). Stating it mathematically, you have

$$\Delta cB = \frac{RdBs}{cR/1000} \times T \text{ mils} = 1000 \times RdBs \times \frac{T}{cR} \text{ mils.}$$

Digitized by Google

Or, by multplying by 3.43 to convert mils to minutes, you have

$$\Delta cB = 3.43 \times 1000 \times RdB_s \times \frac{T}{cR} \text{ minutes}$$

which is,

$$\Delta cB = K \times RdB_s \times \frac{T}{cR} \text{ minutes}$$

where K is equal to 3.43 times 1000, or 3430.

A sample problem will show you how the formula works. Say that RdB_s is equal to 20 yards/second, the increment of time necessary to solve for range prediction is 10 seconds, and the generated present range is 10,000 yards. Solving for the bearing increments at the end of 10 seconds:

$$\Delta cB = 3430 \times 20 \times \frac{10}{10{,}000} = 69 \text{ minutes (approx.)}.$$

The quantity RdB_s, just as with dR, is constantly changing because the values of target angle and relative target bearing change. The integrator also takes the changing values of RdB_s and multiplies them by the infinitesimal time over which each persists, and continuously adds or accumu-

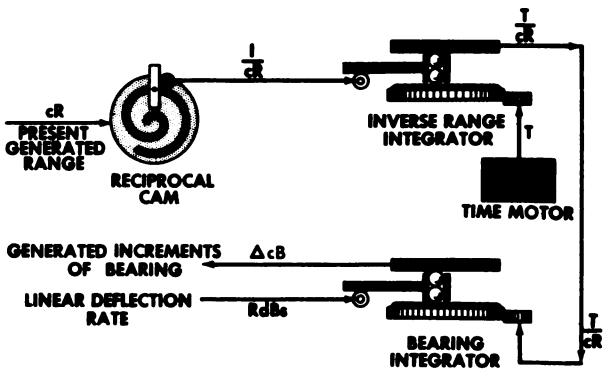


Figure 13—6.—Generating increments of bearing.

Digitized by Google

lates the products. These accumulated products give ΔcB, which represents the total change in bearing at the end of any time interval.

The mechanical units which solve the formula for ΔcB, thereby generating increments of bearing, are shown in figure 13–6. Present range cR, generated from the range-generation mechanism described previously, drives into a reciprocal cam to give $\frac{1}{cR}$. The same time motor that drives the range integrator also drives the inverse range integrator. It only remains to connect $\frac{T}{cR}$ to the disk of the bearing integrator, the carriage of which is positioned by $RdBs$. The roller of the bearing integrator will now turn at a rate proportional to the product of $RdBs$ and $\frac{T}{cR}$. Thus, the output roller rotates an amount proportional to ΔcB.

Increments of Director Train

Increments of bearing have several uses, one of the most important being the calculation of increments of director train, $\Delta cB'r'$ (also called bearing correction), which is supplied to the director. In main battery directors, $\Delta cB'r'$ is received by synchro for the purpose of INDICATING ONLY. Therefore, if the target is momentarily obscured, the director trainer can match dial pointers by turning his handwheel. Consequently, $B'r'$ transmitted to the rangekeeper will be correct as long as ΔcB is correct, or as long as the target maintains the same course and speed.

As shown in figure 13–7, $\Delta cB'r'$ is made up in the rangekeeper by adding ΔcB, Co, and $jB'r'$. Co comes from the ship's gyro by synchro, and $jB'r'$ is made up in the deck tilt computer from $B'r'$ (coming from the director) and L' and Zh (coming from the stable vertical).

Digitized by Google

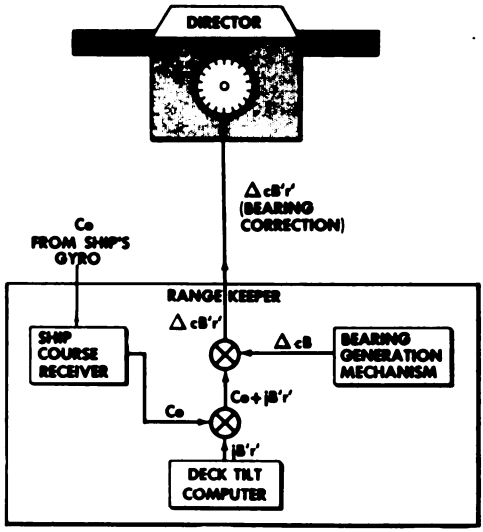


Figure 13–7.—Increments of director train are made up in the rangekeeper and transmitted to the director.

Comparing Generated and Observed Relative Target Bearing

Another important feature of the bearing generation mechanism is that it affords a means of continuously and accurately correcting target angle and relative target bearing. The generator of ΔcB does both of these jobs.

However, before we can be assured that ΔcB is correct, we must COMPARE the observed quantities sent down from the director with the quantities generated by the rangekeeper. This comparison is made at dials mounted in the rangekeeper face. The quantities compared are relative target bearing Br derived from $B'r'$ (coming from the director), and generated relative target bearing cBr. As you already know, cBr is derived from ΔcB, as well as from Co and the initial bearing setting.

Now in order to calculate cBr, it is necessary to find generated true target bearing cB, which is done in a differential. As shown in figure 13–8, cB is equal to the sum of ΔcB and

Digitized by Google

jB. You will recall that *jB* is the initial bearing setting as set up on the SHIP DIAL GROUP shown. The quantity *cB* can be read in degrees and minutes at the outer or ring dials.

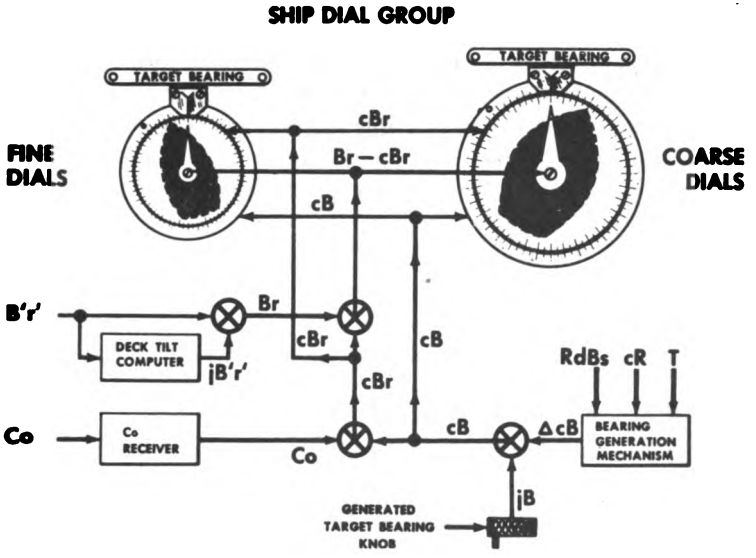


Figure 13–8.—Comparing generated and observed quantities at the ship dial group (surface rangekeeper).

Then *cB* is added to *Co* in another differential to make up generated relative target bearing *cBr*. In turn, *Br* and *cBr* are subtracted in a differential to position the POINTERS of the dial group. These pointers, when read against the ship dial (inner dial), indicate observed relative target bearing *Br*. The pointers are positioned according to the DIFFERENCE between the generated and observed relative target bearing, and will always point to the target bearing indexes if generated target bearing is the SAME as the observed.

Next, look at the coarse and fine dials in figure 13–8; let's see what they do. The coarse dials are calibrated up to 360° and supply a rough reading. At the left of the coarse ship dial group is a smaller, similar group consisting of a fine ship dial, a compass ring, and an observed relative target

Digitized by Google

bearing pointer. These parts rotate with and correspond to the elements of the coarse ship dial group, except that one revolution represents 10° instead of 360°. Reading the two groups together gives closer values than is possible with the coarse ship dial group alone.

The generated target bearing knob shown in figure 13–8 is located at the front of the rangekeeper (fig. 13–1) and is used to make initial corrective settings to generated target bearing. When the rangekeeper is in operation with normal inputs, the knob is used initially to bring the observed relative target bearing pointers of the coarse and fine ship dial groups into line with their respective target bearing indexes. Remembering that $B - Co = Br$, you actually crank in B, or initial bearing jB. Thereafter, corrective settings are made to maintain this alinement whenever necessary.

Correcting Target Angle and Relative Target Bearing

As you've just seen, when the generated and observed quantities are matched, cBr is correct. You will use cBr in all rangekeeper computations. Figure 13–9 shows how cBr feeds into the own ship component solver to enter into the calculations of the X and Y components of the own ship motion vector.

Ignoring movements of the jB crank, you will see in figure 13–9 that increments of bearing actually drive straight through differentials 1 and 2 to continuously correct cBr. It may not be quite as obvious why increments of bearing are driven into differential 3 to change target angle A. The reason why ΔcB can correct target angle is illustrated in figure 13–10.

At the left of figure 13–10, assume own ship and target are at points 1–1 and are maintaining their courses as shown. Assume that an initial true bearing jB has been cranked in, as shown. The angles Co, cBr, and A are also illustrated at points 1–1.

Now when both ships reach point 2–2, both cBr and A have changed to $cBr1$ and $A1$. At point 2–2, lines from

Digitized by Google

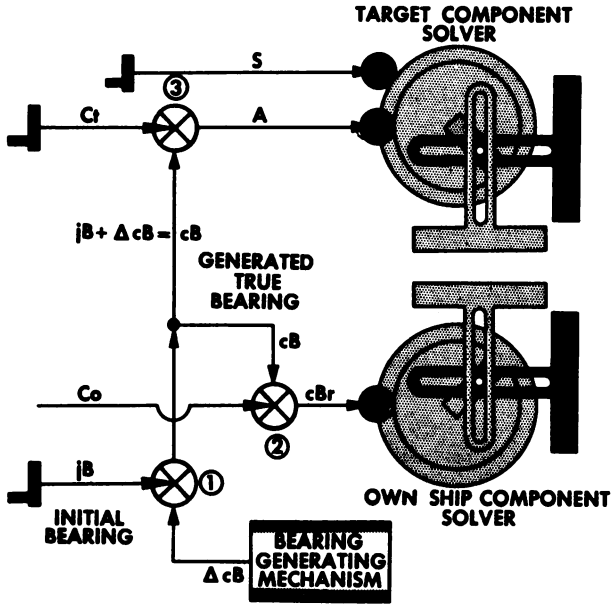


Figure 13–9.—How increments of bearing drive the own ship and target component solvers.

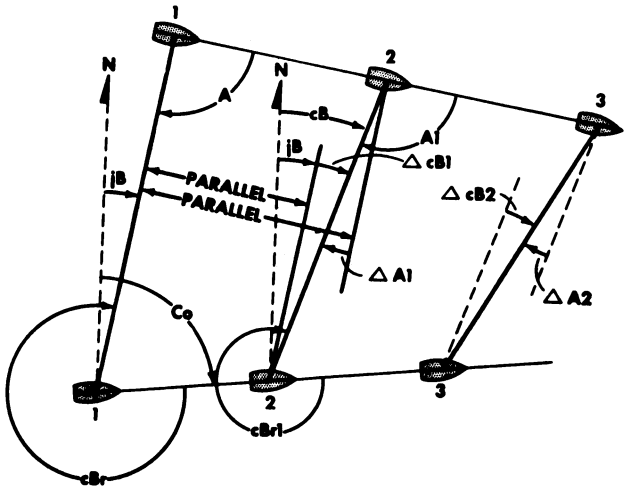


Figure 13–10.—How increments of bearing equal increments of target angle.

Digitized by Google

both own ship and target have been drawn parallel to the original LOS between points 1–1. By referring to the line drawn from own ship parallel to the original LOS, it can be seen the angle $\Delta cB1$ is the angle between the parallel line and the new LOS 2–2. Likewise, an increment of target angle $\Delta A1$, between the parallel line from the target and the new LOS 2–2, is drawn in.

Since the lines from own ship and target are parallel to the original LOS, they are also parallel to one another. Therefore, the new line of sight between 2–2 is a line which intersects two parallel lines. Now, when two parallel lines are intersected by a straight line, the alternate interior angles are equal and so $\Delta cB1$ is equal to $\Delta A1$. That is, increments of target angle are equal to increments of bearing.

This explains why increments of bearing drive the angle-gear of the target component solver in figure 13–9. Thus, once target angle is correct, it will remain correct as long as the target holds the same course and speed.

Upon further inspection of the figure at point 2–2, it will be seen how cB equals jB plus $\Delta cB1$, the first total increment of bearing.

RANGEKEEPER TRACKING SECTION

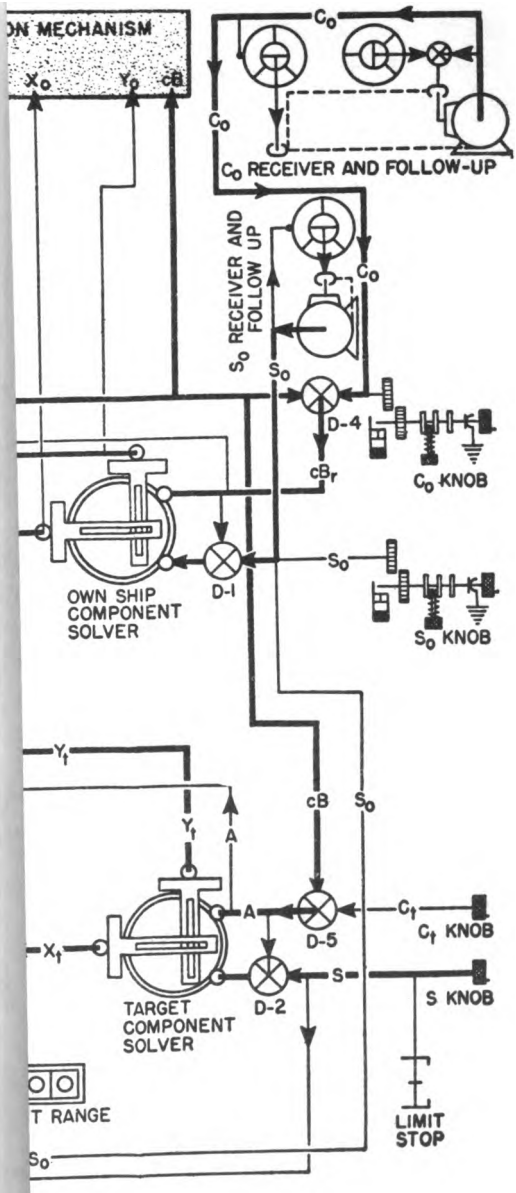
The number one job of any rangekeeper is to produce gun orders. You know from previous chapters that gun train order $B'gr$ is the sum of director train $B'r'$, sight deflection Ds, and trunnion-tilt correction Dz.

Gun elevation order $E'g$ is simply the sum of level angle L', sight angle Vs, and trunnion-tilt correction Vz.

This gives you the gun orders. But how can you tell whether the orders you get from the rangekeeper would make the prejectile connect with the target or splash harmlessly in the drink? This is where the generated rates come in. You can compare the generated quantities with the observed and when they match you have a SOLUTION.

Figure 13–11 shows the generating mechanism of the most widely used surface rangekeeper—the Mk 8. It is simply

Digitized by Google



(Face p. 332)

bined in
enerated
e range-
tracking
ıg.
he heavy
h things

ıted true
mponent
he target
he other
set in by
value of
he target
ıys fixed
e correct
for the

ıormally
ervo fol-
llow-up.
average
s driven
ch *cB* to
er. D–1
mponent

heir out
llow-ups
are used
follow-
es of *Co*

ves into
e target
in gen-

Digitized by Google

Digitized by Google

everything you've studied so far in this chapter combined in one schematic diagram. This print shows how the generated quantities are made up and to what sections of the rangekeeper they are sent. The generating mechanism (tracking section) is the part that KEEPS the range and bearing.

The main steps in the computation are shown by the heavy lines in figure 13–11. The lighter lines indicate such things as connections to dials and auxiliary equipment.

The computation of generated range cR and generated true bearing cB starts with the own ship and target component solvers. Estimated target speed is set directly into the target component solver by a hand knob. Target angle, the other input, is obtained in D–5 combining target course (set in by the hand knob) with the continuously changing value of generated true bearing. Then Ct is set by bringing the target angle dial to the correct value. After that, Ct stays fixed and the changes in cB (due to ΔcB) keep A at the correct value. D–2 is simply a compensating differential for the target component solver.

Inputs to the own ship component solver are normally automatic. So is set in by synchro receiver and servo follow-up, and Co by a pair of synchros and a servo follow-up. Both follow-ups are of the magnetic drag type that average out small fluctuations in the synchro signals. Co is driven into D–4 by its follow-up. There it combines with cB to give cBr, the input to the own ship component solver. D–1 is a compensating differential for the own ship component solver.

The So and Co hand knobs are disengaged in their out position. When they are IN, they de-energize the follow-ups and you can hand-set the quantities. These knobs are used in testing the rangekeeper. Also, if the receivers or follow-ups fail, they can be used to set in telephoned values of Co and So.

Notice that generated relative bearing also drives into D–13, where it is subtracted from observed relative target bearing ($Br = B'r' + jB'r'$). The difference—error in gen-

Digitized by Google

erated bearing—drives the pointers on the ship dial group. These pointers are zero-readers, and, as you already know, they point at the fixed indexes of the own ship dial group when the generated value of relative target bearing agrees with the observed.

The $\dot{Y}o$ and $\dot{Y}t$ outputs of the component solvers combine in D–8 to form range rate dR. This quantity goes to the prediction section, shows up on a dial, and also positions the carriage of the range integrator. The integrator output ΔcR feeds into D–16. The other input to D–16 is the initial value of range, jR, which is set in by a hand knob. When tracking starts, present range is set in on the counter (at the bottom of figure 13–11) by the hand knob to agree with rangefinder or radar readings that show up on the graphic plotter, or that are phoned in.

As tracking progresses cR is adjusted with the jR knob to make it agree with observed present range. When a solution is achieved, the two values—observed range and generated range—will stay in agreement.

Generated present range cR is the output of D–16. It shows up on the present range counter, operates the inverse range cam, and feeds into the ballistic section and graphic plotter.

Linear deflection rate $RdBs$ is obtained in D–10 where the Xo and Xt outputs of the component solvers are added. It feeds into the prediction mechanism, registers at the dials, and positions the carriage of the bearing integrator.

The disk of the bearing integrator is driven by the output of the inverse range integrator. As you learned earlier, this output, $\frac{T}{cR'}$ brings in the element of time. The carriage of the inverse range integrator is positioned by $\frac{1}{cR}$ from the inverse range cam. Thus the output of the bearing integrator is ΔcB, rather than increments of linear deflection in yards. The division by range has been accomplished in the

Digitized by Google

integrator. In differential D–7, ΔcB is combined with jB from the generated bearing hand knob to form cB.

The jB knob is adjusted from time to time as tracking starts to keep the relative bearing zero-reader pointers matched up. When a correct solution is reached, the zero-readers will stay matched without any further movement of the jB knob.

Generated true bearing drives into the prediction mechanism. It also feeds back to the component solvers, where it maintains inputs cBr and A at the correct values, thus completing the regenerative cycle.

Rate Control

The tracking system of a surface rangekeeper gives you a big free premium. It offers you a check on the accuracy of your original estimates of TARGET SPEED and TARGET ANGLE—the only unknown quantities.

With the rangekeeper mechanism you can check your accuracy before you fire. You are setting the same estimated values of target speed and target angle into the rangekeeper mechanism that you need in your predictions, and it is generating values of range and bearing based on your estimates. Every once in awhile you can check generated range against observed range, and you can check generated bearing against observed bearing.

If the generated values continue to run along with the observed values, you know that your estimates were correct. But if the generated values begin to creep away from the observed values, you know that your estimate of target speed or target angle or both must be wrong. You have trustworthy values for own ship course and speed, so any error which exists must be in the target data.

So what do you do?

First, of course, you change the readings on the range counter and the bearing dial to agree with the observed values. You don't want incorrect values going into your

Digitized by Google

ballistic computations because they will throw the gun orders off.

Then you revise your estimates of target movement, cranking in new values of A and S. Now you watch to see whether generated and observed values stay in agreement. Probably they don't, but the error should be smaller. Again you match up the generated and observed values and again you revise the estimated values. After a few such steps, generated and observed values should be running along together. By a process of trial and error, you have found out the correct values of A and S. When this has been accomplished, you have a solution. This trial and error process is called RATE CONTROL.

But there's more behind the story than that. How do you know whether to change the value of A or S, and how much should the erroneous quantity be changed?

You don't know exactly, but you can make a pretty good guess if you have taught yourself how to visualize the situation. Efficient rate control and the achievement of a quick solution demand a great deal of cooperation and practice

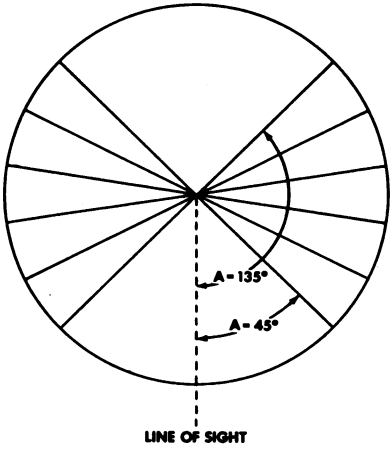


Figure 13–12.—If the target is headed along any of these lines, range rate is chiefly affected by target angle, bearing rate by target speed.

Digitized by Google

within the rangekeeper crew. But the principles of rate control are quite simple if you know what to do about target angle.

Suppose the target is steaming on a course which is at right angles to the LOS, so that target angle is 90° or 270°. *S* has no range component at all, so range rate due to target movement is zero. The only effect of target movement is to change the bearing; that is, to cause a large bearing rate.

In this situation what would be the effect of doubling target speed? Obviously, it wouldn't change the range rate at all, but would double the bearing rate.

Similarly, at any target angle near 90° or 270° you will find that a change in target speed causes only a small change in range rate, but a large change in bearing rate. You can see why in figure 13–12.

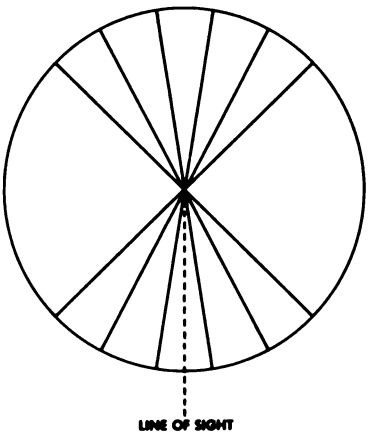


Figure 13–13.—If the target is headed along any of these lines, range rate is chiefly affected by target speed, bearing rate by target angle.

Under the same conditions, it is clear that small change in target angle will have very little effect on bearing rate but will change range rate substantially.

Digitized by Google

On the other hand, suppose the target ship is moving more or less along the LOS, so that target angle is in the neighborhood of 180°. In this case the speed of the ship is devoted almost entirely to opening and closing the range. Thus, any changes in speed will cause a large range rate change, but will change bearing rate hardly at all. And a change in target angle will change bearing rate without causing much change in range rate. This is shown in figure 13–13.

This is just the sort of information you need for rate control. Suppose the target angle is 80°; generated range is decreasing faster than observed range, and generated relative bearing is increasing faster than observed bearing. You can see at once that you must increase the target angle in order to decrease the range rate, and you must decrease the target speed in order to decrease the bearing rate.

Don't try to memorize rules about the changes to make at different target angles. Learn to visualize the situation and to figure out what needs to be done.

Digitized by Google

QUIZ

From the following select the answer (*a*, *b*, *c*, or *d*) which BEST completes the statement or answers the questions.

1. The symbol for generated present range is
   (*a*) dR.
   (*b*) cR.
   (*c*) jR.
   (*d*) R.
2. Generated present range is equal to
   (*a*) $jR+\Delta cR$.
   (*b*) $jR+cR$.
   (*c*) $jR+cR+R$.
   (*d*) $cR+\Delta cR$.
3. What are the two inputs to the range integrator?
   (*a*) jR and Tf.
   (*b*) R and T.
   (*c*) dR and T.
   (*d*) $Rd'Bs$ and T.
4. ΔcR gives
   (*a*) total change in present range.
   (*b*) generated present range.
   (*c*) range prediction.
   (*d*) total change in advance range.
5. dR represents
   (*a*) range rate prediction.
   (*b*) increments of range.
   (*c*) time rate of change of present range.
   (*d*) basic range prediction rate.
6. When target angle is at 90°, linear range rate is
   (*a*) maximum.
   (*b*) increasing.
   (*c*) decreasing.
   (*d*) zero.
7. When target angle is 100°, linear range rate is
   (*a*) decreasing.
   (*b*) increasing.
   (*c*) maximum.
   (*d*) zero.
8. When target angle is 290°, linear range rate is
   (*a*) decreasing.
   (*b*) increasing.
   (*c*) maximum.
   (*d*) zero.

Digitized by Google

9. The range integrator continuously
   (*a*) accumulates the products of dR and time.
   (*b*) adds dR and time.
   (*c*) corrects dR.
   (*d*) furnishes generated present range.
10. When ΔcB is added to the initial true bearing setting you get
   (*a*) $cB'r'$.
   (*b*) cBr.
   (*c*) jB.
   (*d*) cB.
11. When ship's own course is subtracted from generated true target bearing you get
   (*a*) Br.
   (*b*) jB.
   (*c*) cBr.
   (*d*) $jB'r'$.
12. The zero-reader pointers of the ship dial group of the Mk 8 range-keeper are driven by
   (*a*) $B-cB$.
   (*b*) $Br-cBr$.
   (*c*) $jB-cB$.
   (*d*) $jB-\Delta cB$.
13. If generated relative target bearing creeps away from solution, it is an indication that
   (*a*) target angle or target speed is in error.
   (*b*) initial bearing setting is in error.
   (*c*) either initial bearing setting or target angle is in error.
   (*d*) either initial bearing setting or target speed is in error.
14. Increments of director train is equal to
   (*a*) $cB+cBr+Co$.
   (*b*) $\Delta cB+Br+jBr$.
   (*c*) $\Delta cB+jB'r'$.
   (*d*) $\Delta cB+Co+jB'r'$.

Digitized by Google

CHAPTER 14

RANGEFINDERS

TRIANGULATION

Ancient Egyptian surveyors first used TRIANGULATION to measure the distance to a point they couldn't get at with a measuring stick, and we still use it. Figure 14–1 illustrates the principle of triangulation. Suppose you are at point A and you want to know the distance to point P. You measure off any handy distance AB at right angles to AP. Then, at point B you measure the angle θ between BP and BC which is parallel to AP.

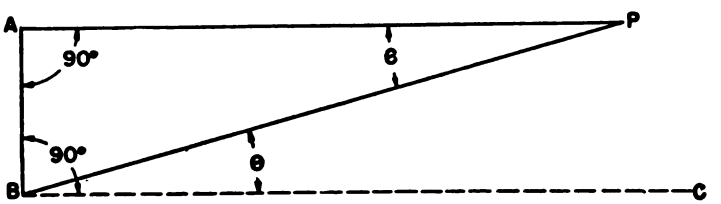


Figure 14–1.—Measuring distance by triangulation.

You can see from the figure that angle APB will also equal θ. Then you know that—

$$\tan \theta = \frac{AB}{AP}.$$

In a rangefinder, the distance AB is called the BASE and is written B. It is the distance between the end reflectors of

Digitized by Google

the instrument. AP, of course, is the range R. So the triangulation formula can be written for rangefinders as

$$\tan \theta = \frac{B}{R}. \qquad (1)$$

Now, obtain a trigonometric table (appendix IV) and study the tangents for the first few degrees. You'll notice that the tangent of 2° is almost exactly twice the tangent of 1°, the tangent of 3° degrees is about three times that of 1°, etc. This will be nearly true up to 9° or 10°. In other words, for small angles, the tangent of the angle is directly proportional to the angle itself, or

$$\tan \theta = (\tan 1°)\ \theta = .0175\ \theta.$$

There are 3,600 seconds in a degree. So if θ is written in seconds instead of in degrees, you have

$$\tan \theta = \frac{.0175\ \theta}{3600}$$

and, to arrive at a more suitable form, divide both numerator and denominator by .0175—

$$\tan \theta = \frac{\theta}{206{,}265}. \qquad (2)$$

Then, by substituting the value of $\tan \theta$ in (2) for that in (1), the triangulation formula can be written

$$\theta = 206{,}265\ \frac{B}{R} \text{ seconds.}$$

The small angle θ is called the PARALLACTIC ANGLE. It is the job of any rangefinder to measure this angle.

Whether he realizes it or not, every man with two eyes has a built-in rangefinder of a sort. Your brain has learned to sense distance by the angle your eyes are turned to bear upon an object—in effect, among other things, the brain measures the parallactic angle. But your eyes are spaced close together, and therefore you can judge only relatively short distances accurately. The stereoscopic rangefinder is really just a device to improve the performance of your own

Digitized by Google

built-in rangefinder; it simply magnifies the parallactic angle for you by increasing the distance between your eyes.

Spreading the Eyes

Here's how you can spread your eyes apart. A penta prism will turn a ray of light exactly 90°. Suppose you took a stiff metal bar, say 15 feet long, and mounted a penta prism at each end. Now turn the bar toward a distant object so that a line from the left-hand prism to the object is perpendicular to the bar as in figure 14–2.

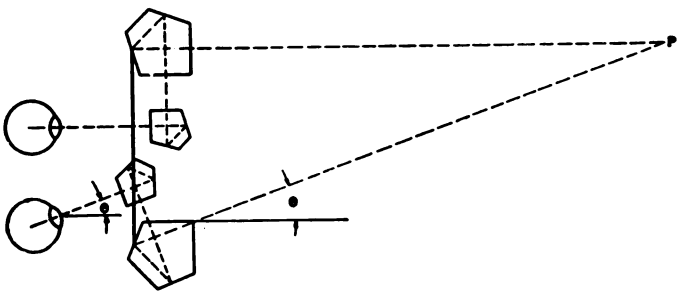


Figure 14–2.—How to increase the base-length of the eyes.

Now a ray of light from the distant target to the left prism will be turned 90° and will travel inward along the bar and parallel to it. But a ray from the target to the right prism will make a rather large parallactic angle with the bar—more than 70 times the parallactic angle which the eyes would see at the same distance. This second ray will be reflected in along the bar, but making an angle θ with it.

You could use a pair of penta prisms as shown or some other arrangement of mirrors and prisms at the center of the bar, spaced as far apart as the eyes. This arrangement would again turn each ray through 90°, directing them into the eyes. Then these two rays enter the eyes divergent by an amount equal to the parallactic angle θ, which results from a 15 foot base rather than the short distance between the eyes Thus, your two eyes would see the object with the same paral-

Digitized by Google

lactic angle as if you had spread your eyes 15 feet apart. This increases the maximum distance at which the eyes can detect differences in range by more than 70 times. You can figure out this increased rangefinding ability by dividing 15 feet by the distance between your eye pupils.

You have now seen two ways in which the range and accuracy of the human rangefinder can be improved. The stereoscopic rangefinder combines both these methods. You can readily see how this can be done. Suppose, in figure 14–3, the rays emerging from the center prisms had been directed into the objectives of a pair of telescopes. Then the parallactic angle—already increased by the increase in base—would be multiplied again by the magnifying power of the telescopes. Thus, for example, an instrument with a 15-foot base and a 24X telescope would have about 1,700 times the range sensitivity of the unaided eye.

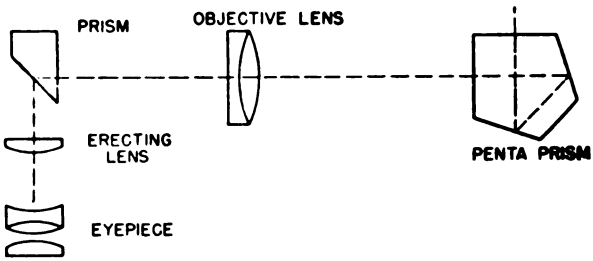


Figure 14–3.—One side of a simple stereoscopic rangefinder.

In order to save space, some of the optical elements of the telescopes are mounted inside the rangefinder tube. A simplified arrangement would be like figure 14–3. Only one side of the instrument is shown.

The addition of the lens system of figure 14–3 magnifies the parallactic angle by an amount M. This changes the rangefinder formula to

$$\theta = 206{,}265 \frac{BM}{R},$$

where B and R are expressed in yards.

Digitized by Google

MEASURING RANGE

So far, you have an excellent spotting glass. That is, an operator can tell very accurately which of two distant objects is farther away. But he still can't tell just how far away either object is. To measure distance, another unit must be introduced into the instrument.

The Measuring Wedge

In figure 14–4, a thin refracting prism, or measuring wedge, has been inserted in the right-hand side of the instrument. A ray of light is coming from the penta prism making an angle θ with the axis of the rangefinder. This angle is the parallactic angle.

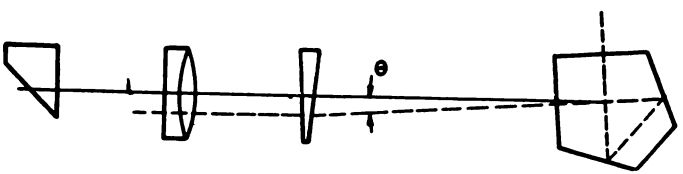


Figure 14–4.—The measuring wedge.

When the ray enters the thin prism it will be bent toward the thicker edge of the prism. The prism reduces the angle between the ray and the axis of the instrument. To an operator looking through the eyepieces, the target would appear to have moved farther away.

If the prism has just the right thickness, the ray of light will be bent parallel to the axis of the instrument. You can see that for every parallactic angle—i. e. for every distance—there will be a particular prism which will bend the rays exactly parallel to the axis.

The operator can measure the parallactic angle, and the corresponding distance, by seeing just how thick a prism he needs to bring the ray parallel to the axis. In other words, the prism he needs to reduce the parallactic angle to zero.

Digitized by Google

But how is the operator going to tell when the ray is parallel to the axis? At the focal plane of the objective lens on each side of the instrument is located a reticule with a diamond-shaped target—called the WANDERMARK OR RANGING MARK. These marks are in the center of the reticules on the optical axis of the lenses. When the eyepieces are focused so that the operator sees a sharp image of the target in each eye, he will also see a sharp image of the ranging mark. The two images in each eye will blend stereoscopically.

Now if the angle between the rays coming from the two RANGING MARKS is less than the parallactic angle between the rays from the target, the mark will appear to the observer to be more distant than the target. And if the angles are the same, the target and the ranging mark will appear to be at the same distance.

The ranging marks are located on the optical axes of the telescopes. Hence the rays from them are parallel to the two eyepiece axes and are parallel to each other. Therefore, when the ranging mark and the target appear to the operator to be at the same distance, he knows that the rays from the target have been bent by the measuring prism enough to make them parallel to the axis of the instrument.

In this manner, the operator can tell which thickness of prism cancels out the parallactic angle, and from this he can tell how far away the target is.

Operation of the Measuring Wedge

A rangefinder operator would be a mighty busy man if he had to try out several thousand different prisms in order to measure a range. He needs some convenient way of varying the amount by which a single refracting prism bends the light. He does this by rotating the prism, or MEASURING WEDGE.

Any prism, as you know, bends light toward its thick edge. Thus, if the prism is placed with its thick edge up, as in figure 14–4, the ray will be bent forward or backward. This is the bending you are interested in. Now if the prism is

Digitized by Google

turned 90° it will bend the ray just as much, but the bending will all be up and down. There will be no fore and aft bending.

If the prism is turned to some angle a in between the vertical and horizontal, the bending will be partly up and down, and partly fore and aft. This is shown in figure 14–5.

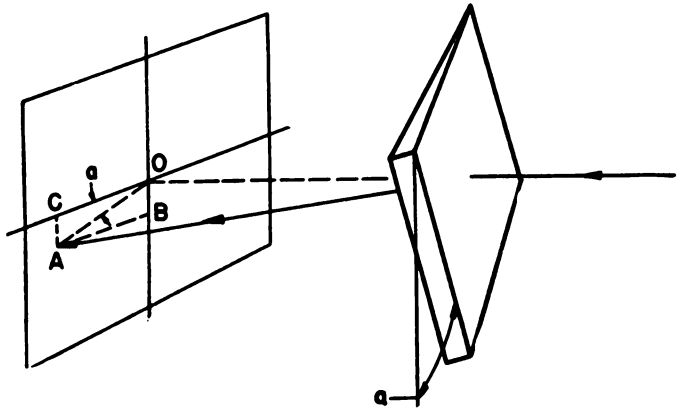


Figure 14–5.—Effect of rotation of the measuring wedge.

In the figure, the ray passing through the prism has been projected onto a screen to show the amount of bending. On the screen, AO measures the total amount by which the prism bends the ray. It will have the same length for any position of the prism. OC measures the amount of fore and aft bending, and its length will depend upon the rotation of the prism.

It is only fore and aft bending that affects the apparent distance of the target. Rotation of the prism enables the operator to bend the ray fore and aft by any amount he desires.

One difficulty remains. The upward and downward bending must be eliminated.

This can be done by a second prism. If this prism, a duplicate of the first, is rotated an equal amount in the opposite direction, it too will cause both a fore and aft

Digitized by Google

and an up and down bending. But the up and down bending caused by the two wedges will be in opposite directions and will cancel out. The fore and aft bending of the two wedges will add together, as shown in figure 14–6. On the screen, the first prism causes bending OA, the second AB. The resultant movement is entirely fore and aft and amounts to OB.

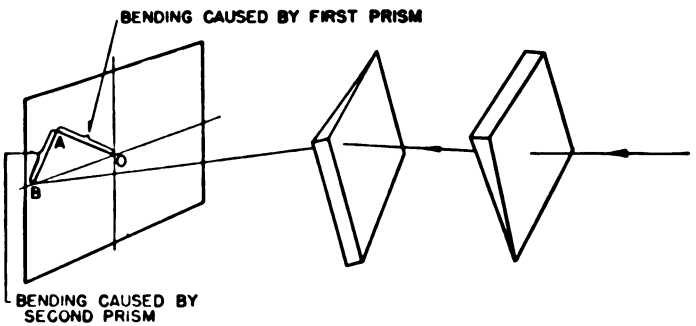


Figure 14–6.—Effect of rotating two wedges.

Maximum bending to left will be obtained when the two prisms have their thick edges side by side, vertical, and to the left. As one of the prisms rotates clockwise and the other counterclockwise, the amount of bending to the left will decrease until, after 90° rotation, neither prism is causing any fore and aft bending. All of the bending of one is up, and the other down. As the prisms continue to rotate, they will begin to cause bending to the right, which will reach a maximum after 180° rotation.

The amount of rotation of the prisms required to make the target and the ranging mark appear to be at the same distance measures the parallactic angle. Thus, it measures the range.

If a scale is mounted on one of the prisms to rotate with it, it can be graduated in yards range, and the range can then be read directly.

Digitized by Google

The structural frame of a modern Navy rangefinder consists of three long tubes, one inside the other. (See fig. 14–7.) The OUTER TUBE is simply a strong airtight cover to protect the optical and mechanical parts. Heavy wrappings of insulating material prevent fluctuations in the temperature of the working parts of the rangefinder. This tube is gas-tight and is kept filled with helium or nitrogen gas under slight pressure. The gas serves two purposes: (1) It keeps oxygen away from the lenses and prisms in order to retard aging of the optical glass and cementing materials. (2) And since the gas is put into the instrument dry, it prevents condensation of moisture on the inner surfaces.

The outer tube has a pair of rings around it, one near each end. These rings attach the rangefinder to its mount in a director or turret.

Mounted within the outer tube is the INNER TUBE. This is the main structural frame of the instrument. It carries nearly all the optical and mechanical working part. The only important exception is the eyepiece group, which is fastened to the outer tube.

The inner tube is mounted inside the outer tube by means of two bearings. The right-hand bearing is constructed to permit a little movement back and forth along the axis of the rangefinder. Thus, if either of the tubes expands or contracts as a result of external stresses or temperature changes, the other tube will not be affected.

Within the inner tube is the OPTICAL TUBE. (See fig. 14–7.) This is a short rigid tube, machined from a steel forging. It contains those optical parts for which rigid alignment is necessary. These parts are the objective lenses, reticules, and the ocular prisms which bend the light toward the eyes. The optical tube is bearing-mounted in the inner tube so that it will not be affected by expansion and contraction.

The penta prisms needed in large rangefinders would be

Digitized by Google

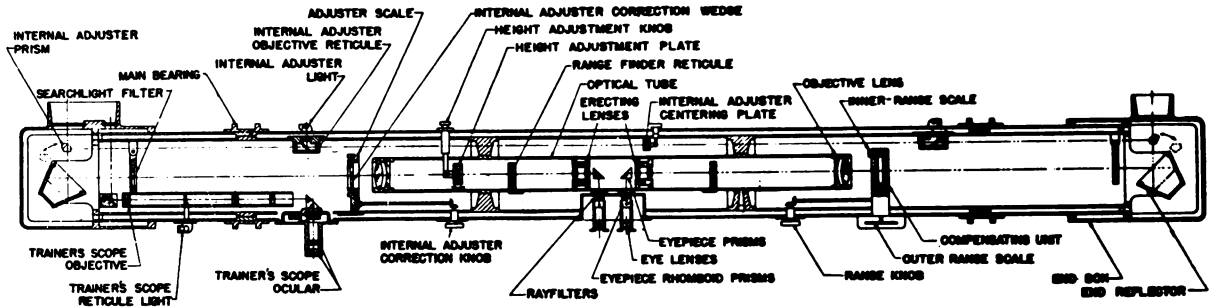


Figure 14–7.—Construction of a simple rangefinder.

Digitized by Google

so large that they would be hard to manufacture. So two mirrors, mounted in a box frame, are used instead. The optical effect is the same as a penta prism. These assemblies are called END REFLECTORS.

The end reflectors are attached by a rigid framework to the ends of the inner tube. They are protected by an air-tight END BOX attached to the outer tube.

An optical glass window is provided in the end box to admit light to the end reflectors. These windows are part of the optical system of the instrument and MUST NOT be moved. They are slightly wedge shaped so that they bend the entering rays by a very small angle. This bending is used in the last step in the alignment of the instrument at the factory. The end windows are rotated to take out any remaining error. Then the windows are cemented in place. You can readily see that the instrument would be fouled up if the windows were moved by anyone other than an optical repairman.

Adjustments of the Rangefinder

The optical elements directly used in ranging have been covered, but, in addition, the modern rangefinder has a number of adjustable features in the main optical system. Further, it contains several auxiliary optical systems.

The first adjustable feature is in the eyepiece. Just as in a telescope, the eyepieces must be focused to adjust the emerging rays to the degree of parallelism or convergence which is most comfortable for the operator's eyes. You make this adjustment separately for each eyepiece by rotating the focusing ring.

Do NOT close one eye when focusing the other eyepiece. Closing one eye changes the focus of the other. Have someone cover one end window of the rangefinder and then, with both eyes open, focus one of the eyepieces.

You will find that you generally use the same diopter setting on the eyepiece scale when focusing different rangefinders. Learn the setting for each of your eyes. Then always turn the eyepiece to that setting.

Digitized by Google

Another figure you should memorize is your own inter-pupillary distance. This is simply the distance between the pupils of your eyes when your eyes are relaxed. You'll find instruments for measuring this distance aboard all ships. The distance is measured in millimeters, and the rangefinder is built for inter-pupillary distances running from 60 to 70 mm. If you fall outside that range, you just can't operate a stereo rangefinder.

The rangefinder is so built that the distance between the eyepieces can be adjusted. Figure 14–8 shows how this works. Light rays coming along the axis of the instrument are bent toward the observer by the ocular prisms. Then the rays are reflected downward by a pair of rhomboid prisms, before they enter the eyepiece lenses.

You can see that rotation of the rhomboid prisms about the

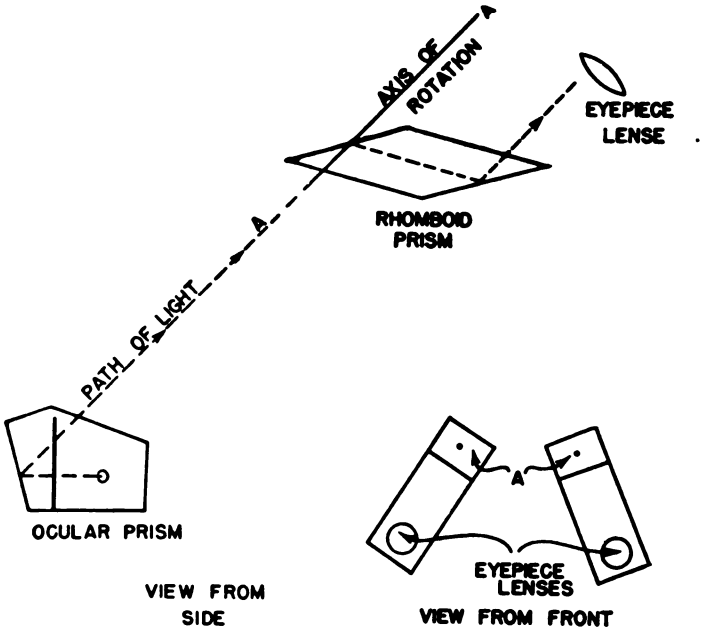


Figure 14–8.—How the inter-pupillary distance adjustment is made.

Digitized by Google

axis A—A will not change the length of the path of the light—in fact rotation of these prisms will not change the optical characteristics of the system in any way. But by rotating the prisms, the distance between the eyepieces can be changed to fit your particular inter-pupillary distance.

The Height Adjustment

To maintain stereoscopic vision, the images arriving from the two end reflectors must be at the same height. This adjustment is made by tilting a piece of glass, as shown in figure 14–9.

You remember what happens when you refract a ray of light through a plate of glass with parallel sides—the ray is moved to one side without being changed in direction. And the amount it is moved depends upon the angle at which it strikes the plate.

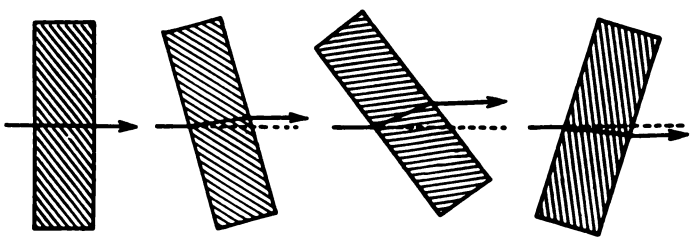


Figure 14–9.—Principle of the height adjuster.

The height adjuster uses this principle. The device is simply a disk of glass, with parallel sides, inserted in the left-hand optical system (the one opposite the ranging wedges). The disk is mounted on bearings so that it can be tilted in either direction. Tilting it, as shown in figure 14–9, will raise or lower the image of the target at the focal plane. A knob on the side of the rangefinder controls the tilt of the plate.

One way to make the height adjustment is to aim the rangefinder at some distant target such as the horizon. Set the

Digitized by Google

range knob at minimum range. This should make it possible to break stereoscopic vision and to see two separate images of the ranging mark and of the horizon. If one mark appears farther above the horizon than the other, move the height adjuster knob to equalize the distance.

Another system is to cover one end window of the rangefinder—then looking through the other eyepiece, train and elevate the rangefinder to a position so that the bottom point of the ranging mark is just touching some target on the ship, such as the jackstaff. Now cover the other window instead. Train the rangefinder slightly, without elevating or depressing it, to bring the ranging mark over the same target. With the height adjusting knob, make the bottom of the mark just touch the target.

Internal Adjuster Correction Wedge

The rangefinder is a precision instrument built with extreme care—but like any instrument it can get out of adjustment. Many things can cause it to lose its precise alinement. The commonest trouble is change in temperature causing expansion and contraction of the various parts. When this happens, the instrument will give incorrect readings, and some means must be provided to compensate for the error. This is the purpose of the Internal Adjuster Correction Wedge.

The correction wedge is essentially a second ranging wedge. It is placed in the LEFT optical system outboard of the optical tube as shown in figure 14–7. It's a circular refracting wedge, which will bend the incoming rays by varying amounts as it is rotated. Unlike the ranging wedge, it is a single wedge, not a pair of wedges rotating in opposite directions. Hence, the correction wedge bends the ray up and down as well as from side to side. Fortunately, movements of the wedge are ordinarily so small that this doesn't matter. And in any case, up and down bending of the rays introduced by the wedge can be eliminated by changing the height adjustment.

Digitized by Google

The correction wedge described above is used when comparing the rangefinder readings with some known distance. Suppose it is known that the distance to some point is 7,300 yards. A careful range is taken, and the range scale reads only 7,000 yards. This 300-yard error must be eliminated.

The next step is to set the range scale at the known range to the target—in this case 7,300 yards. Now range on the target WITH THE CORRECTION WEDGE without touching the range knob. When the target and the ranging mark appear to be at the same distance, read the scale attached to the correction wedge—known as the adjuster scale. Repeat this operation about ten times, keeping a record of the readings.

Finally set the average value obtained from the ten readings onto the adjuster scale. The instrument should now be in adjustment, and ranging with the ranging knob should give correct values at any range. The correction knob is usually covered with a screw cap when not in use, to prevent disturbing the setting.

This procedure is easy enough. The difficulty is to find a known range to check on. Sometimes a rangefinder can be taken ashore and checked on a measured distance, but this is rarely practical. In certain ports, range checking charts have been made up, giving the distances between various conspicuous objects. The position of the ship can be established by taking bearings on several known points, and the distance to the points shown on the chart can thus be calculated.

A more practical method at sea is to check the rangefinder against radar ranges or against ranges obtained with a longer-base rangefinder. Checking against radar is particularly valuable because radar ranges are much more accurate than rangefinder ranges at distances greater than about 5,000 yards provided the radar is in good adjustment.

In either case, the procedure is to obtain the correct range to a well-defined target and then use the internal adjuster correction knob as before.

Digitized by Google

It is also possible to use the moon or another heavenly body as a known range of infinity. Set the range scale on infinity and then range on the moon with the compensating wedge. But this method has an important disadvantage—temperature conditions at night are quite different from those in the daytime, and a rangefinder which is in adjustment at night may be seriously in error the next day.

The Internal Adjustment

The above methods can be used for occasional checking of the rangefinder. But they are not available for constant hour by hour checking. Nevertheless, temperature and other conditions do change hourly, and an almost constant check on the rangefinder is needed if you want accurate results.

The INTERNAL ADJUSTMENT of the rangefinder is provided to meet this need. This is a system which sets up an artificial target of known range INSIDE THE RANGEFINDER. The placement of the parts of the internal adjuster system is shown in figure 14–7.

You can see how the internal adjustment is made in figure 14–10, which is a schematic diagram of the entire optical system of the rangefinder.

Look at the internal adjuster system at the top of the drawing. The distance between the two adjuster objective lenses is equal to their focal length. Fastened to each of the lenses is a reticule carrying a target mark, usually consisting of a pair of vertical lines. Each of the target marks is thus located in the focal plane of one of the lenses. Outboard of each lens is a transparent reflector plate.

Consider the left-hand reflector. Light from the small internal lamp is reflected from the reflector plate (fig. 14–7), and illuminates the left target mark. Since this mark is in the focal plane of the right objective, rays from the mark will emerge from the right objective parallel to each other. Some will be reflected by the right reflector and be lost, but some will pass through.

Digitized by Google

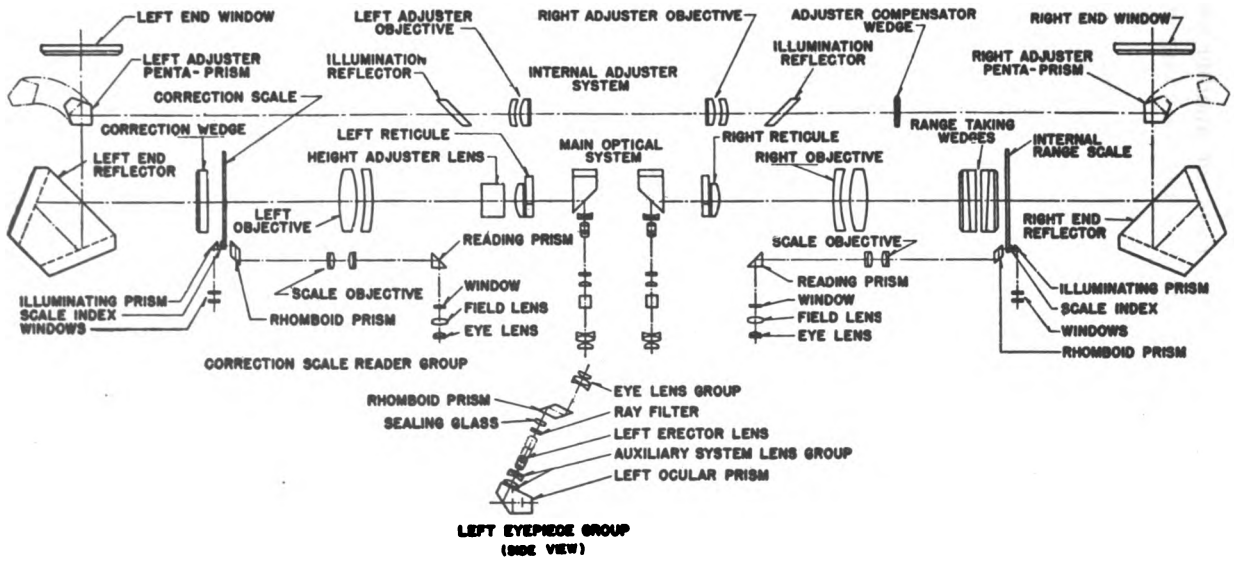


Figure 14–10.—Optics of the rangefinder.

Digitized by Google

At the same time, the right target mark, illuminated by the right reflector, is sending out rays which emerge from the left objective parallel to each other.

In the end boxes are a pair of small penta prisms. These are placed to turn the rays coming from the adjuster objectives through 90° and direct them into the end reflectors of the main optical system. Ordinarily, these prisms are swung back out of the way. But when you want to use the internal adjustment, you rotate the INTERNAL ADJUSTER DRIVE KNOB. This cranks the penta prisms into place and also closes shutters over the end windows to prevent stray light from entering.

If the two pairs of target marks are on the optical axes of the adjuster objective lenses, the rays from them will emerge parallel to the axes. Thus, the two sets of rays will be in the same line, and when they have been turned 90° by the penta prisms they will be parallel to each other. An operator will receive an image of one pair of marks in each eye and will merge them stereoscopically into a single target at an infinite distance.

But if one pair of marks is slightly offset from the optical axis, the rays from it will emerge at a slight angle to the axis. This is done in modern rangefinders. The offset is made such that the angle between the two rays coming into the end reflectors from the penta prisms will be equal to the parallactic angle of a target at 6,000 yards.

Thus the operator will see the images of the target marks as if they were 6,000 yards away. If he sets the range scale at 6,000 yards, the ranging mark and the internal adjustment target should appear to be at the same distance. If they don't, the operator turns the internal adjuster correction knob to bring them together. This is done ten times, and the average correction scale reading is set on the scale.

You'll notice in figure 14–10 that there's an adjusting wedge in the internal adjustment optical system. This is used only in making factory adjustments, and cannot be moved from outside the rangefinder.

Digitized by Google

The internal adjustment is easier to make if the ranging mark is centered between the two vertical lines forming the adjustment target. If it isn't centered, you should center the mark by turning the ADJUSTER SIDE ADJUSTMENT KNOB (also called the collimator adjustment knob). What this knob does is to pivot the whole adjuster system slightly on its left bearing.

To take an internal adjustment, proceed as follows:

1. Turn the adjuster drive knob as far as it will go. This swings the penta prisms into place and closes the end windows.
2. Looking into the eyepieces, center the ranging mark between the lines of the adjuster target. Use the collimator adjustment knob.
3. Set the internal range scale at 6,000 yards, or whatever internal range is used on your instrument.
4. Uncover the internal adjuster correction knob and rotate it until the ranging mark and the adjuster target appear to be at the same distance.
5. Read the correction scale.
6. Repeat ten times. Average the adjuster scale values. With the internal adjuster correction knob, set the average value onto the adjuster scale.

It is considered good practice to make an internal adjustment every hour during a watch or whenever a pause in ranging occurs during action or drill. It is essential that an internal adjustment be made whenever a NEW OPERATOR takes over, because the corrector setting includes an allowance for consistent personal errors as well as for instrument errors. Correction of these errors will be discussed in greater detail later in the discourse on A and B curves.

READING THE SCALES

Two range scales are provided on modern rangefinders—an external scale and an internal scale. These scales are shown in both figures 14–7 and 14–10. The internal scale is the more important one. This is a ring scale directly at-

Digitized by Google

tached to the ranging wedge of the instrument and turning with it. Its position is always an accurate indication of the actual setting of the ranging wedge, with no possibility of mechanical lost motion.

The internal range scale is read by means of an auxiliary reading telescope built into the rangefinder. As you can see from figure 14–10, the reading telescope consists of an arrangement of lights and prisms to illuminate the scale, an objective lens, a collective or field lens, and an eye lens. The window shown in the illuminating system is to protect the airtight seal of the instrument.

The external range scale is a second dial placed near the outside of the rangefinder so that it can be read through a window without the aid of artificial light. Remember, the external scale is less trustworthy than the internal one because of the gearing between it and the ranging wedge. Any backlash or lost motion in the gears will show up on the outer scale as an error.

Normally you'll read the internal scale only. The external scale is used if the illuminating circuit for the internal scale fails. An occasional check should be made to see that the two scales are giving the same reading. If a discrepancy is found, it may indicate excessive lost motion (which could probably also be felt in the ranging knob) or that the adjustable coupling between the external scale and the wedge is out of adjustment. In either case, repairs should be made by an optical repairman.

The internal adjuster correction wedge is read by means of an internal adjuster scale only. There's an auxiliary optical system similar to that of the internal range scale. The adjuster scale is calibrated in UNITS OF ERROR from 0 to 120—a unit which is explained a little later. The normal setting is about 60 units.

LIMITS OF ACCURACY

Range measurement with the stereoscopic rangefinder is based on the ability of the operator to see whether the target

Digitized by Google

and the ranging mark appear to be at the same distance. That is, accurate measurement depends upon the ability of the operator's eyes to detect whether the rays coming through the eyepiece from the target are parallel to the rays from the ranging mark.

You remember that the smallest difference of parallactic angle which the eye can detect is 12 seconds. This means that, when the rays from the target and from the ranging mark appear to be parallel, they may actually make an angle of nearly 12″ with each other.

Thus, when the rangefinder scale reads, say, 10,540 yards, the actual distance to the target may be greater or less than 10,540 yards. The error may be any amount which does not change the parallactic angle observed at the eye by more than 12″.

This distance, by which the scale value of range is uncertain, is called the UNIT OF ERROR. It is the distance in yards by which the range will change if the parallactic angle at the eye changes 12″.

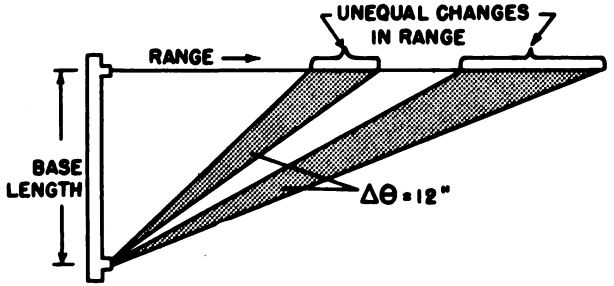


Figure 14–11.—How the unit of error increases with range.

You can readily see that the value of the unit of error will become smaller as the base length and magnification of the instruments are increased. And figure 14–11 shows you that the value of the unit of error will be different at different ranges. The greater the range, the greater the unit of error.

It is easy to figure out the exact value of the unit of error from the rangefinder formula repeated below:

Digitized by Google

$$\theta = 206{,}265 \frac{BM}{R}. \qquad (1)$$

To simplify things, let's first substitute a symbol α for 206,265 BM. This gives

$$\theta = \frac{\alpha}{R}. \qquad (2)$$

Now suppose θ in the formula is increased by 12″. Then R will be decreased by a small amount, e, which will be the unit of error. We can now modify our rangefinder formula in (2) to include the new values resulting for a 12″ increase of θ, to give

$$\theta + 12 = \frac{\alpha}{R - e}. \qquad (3)$$

Substracting (2) from (3),

$$12 = \frac{\alpha}{R-e} - \frac{\alpha}{R},$$

and simplifying,

$$12\ R(R-e) = R\alpha - (R-e)\alpha.$$

Then, by factoring and simplifying:

$$12\ R(R-e) = e\alpha. \qquad (4)$$

Since e is small with respect to R, $R(R-e)$ is almost equal to R^2. Making this substitution in (4),

$$12\ R^2 = e\alpha. \qquad (5)$$

Next replace α in (5) with the original values of the rangefinder formula, and solve for e:

$$e = \frac{12\ R^2}{206{,}265\ BM}$$

$$\text{or, } e = \frac{.000582\ R^2}{BM}. \qquad (6)$$

Finally, equation (6) can be made into a more convenient form by multiplying the numerator and denominator by 1000^2, hence

Digitized by Google

$$e = \frac{58.2\,R^2}{BM\,1000^2}$$

$$\text{or, } e = \frac{58.2}{BM}\left(\frac{R}{1000}\right)^2. \qquad (7)$$

In this formula, e is the range error in yards due to one unit of error:

B is base length of rangefinder in yards;
M is magnification of rangefinder;
R is range in yards;
58.2 is a constant valid only when the operator stereo-acuity is 12 seconds.

The formula proves that the unit of error becomes less as base length and magnification of the instrument increase. In short, big rangefinders are more accurate than little ones—just as you would expect. It also shows that the size of the unit of error in yards increases as the square of the range. This means that you can expect four times the error when you double the range. Figure 14–12 tabulates the values of the unit of error at different ranges for a 15-foot rangefinder with 24X magnification.

RANGE YARDS	U. OF E. YARDS	RANGE YARDS	U. OF E. YARDS
1,200	0.7	14,000	95.0
1,500	1.1	16,000	124.1
2,000	1.9	18,000	157.1
2,500	3.0	20,000	193.9
3,000	4.4	25,000	303.0
4,000	7.8	30,000	436.0
5,000	12.12	35,000	594.0
6,000	17.5	40,000	776.0
8,000	31.0	45,000	982.0
10,000	48.5	50,000	1,212.0
12,000	69.8	.....	.....

Figure 14–12.—Values of unit of error for a typical rangefinder.

Digitized by Google

It may prove interesting to double check a few values in the chart. Using equation (7), first calculate the left-hand factor

$$\frac{58.2}{5\times 24}=.485.$$

Notice that this is a constant for a given rangefinder assuming the operators stereo-acuity to be 12 seconds. The right-hand factor of equation (7) is simply range in thousands of yards squared. Thus, for a range of 2500 yards

$$e=.485,2.5)^2=3.0 \text{ yards.}$$

And, for a range of 16,000 yards,

$$e=.485(16)^2=124.1 \text{ yards.}$$

Next, let's find the range error at 16,000 yards when you substitute a 30-foot rangefinder, assuming the same stereo-acuity for the operator:

$$\frac{58.2}{10\times 24}(16)^2=62.0 \text{ yards.}$$

Notice that, other things being equal, the error is only half as great when the base length of the rangefinder is doubled.

An important use of the unit of error is in comparing the performance of different rangefinder operators. Suppose that Joe Doaks using a 30-foot 24X instrument measures the range to a target at 35,000 yards. Comparison with a radar reading indicates that he's 1,500 yards off. Elmer Zilch measures a 12,000-yard range with a 15-foot 12X rangefinder and is 500 yards off. Which is the better operator?

From the formula, the unit of error of the big instrument at 35,000 yards is 297 yards. Joe shows a little more than 5 units of error ($1500\div 297=5$ approximately). Not good, not bad. The unit of error for the other rangefinder at 12,000 yards is 140 yards. Elmer is 3.6 units off.

Zilch is your man.

You can also use this formula when applying corrections to a rangefinder by means of the correction wedge. Suppose the plotting room is receiving range readings on a target

Digitized by Google

from five different rangefinders. The graphic plotter operator notices that the readings from Range 3 are running higher than those received from the other stations. He can see how much the variation is at the range of the target. He computes Range 3's unit of error at that range (or gets it from a table) and figures out how many units of error the instrument is off. Then he tells the rangefinder operator to change his correction scale setting by that number of units.

You also have to work with the unit of error whenever you get a chance to check the rangefinder against known ranges. You'll use the internal adjustment constantly as a check on the rangefinder. But internal adjustments themselves can go wrong, and you should never rely on them exclusively. Check on a known range whenever you get the chance.

Here's how you use a known range to check the internal adjustment:

You have adjusted your instrument by means of the internal adjustment. Then you range on a target at known distance with good conditions for observation—but you get an erroneous reading. You convert the error in yards into units of error, by dividing by *e*, and make a change or offset in the internal adjuster scale setting to correspond. When you increase the reading on the adjuster scale it will make the rangefinder read a lower value at the same range. You keep a record of this offset to the internal adjuster scale setting. Then in the future, when you complete an internal adjustment, you offset the scale by the same amount.

You may find that the amount of this offset—which is called the INDEX CORRECTION—is different at different ranges. The thing to do in this case is to make a chart, plotting calibration correction against range. Then, when ranging on surface targets, you can pick the right correction from the chart. Such a chart is called a B-curve.

Another chart, called the A-curve, is a plot of the unit of error for a specific operator. He can then apply these corrections to the internal adjuster upon manning his range-

Digitized by Google

finder. Of course, as you will see shortly, these corrections are made in terms of adjuster scale units.

A-CURVE

The A-curve shows the value in yards that a change of one unit of the adjuster scale will produce at various ranges. At least three objects X, Y, and Z, at different ranges are selected.

The operator then takes an accurate internal adjustment check. Ten ranges are taken on object X and recorded. The adjuster scale is then deliberately set 10 units too high, and ten more ranges are taken and recorded. The same is repeated for a setting 10 units too low. The internal adjuster scale has been offset a total of 20 units (+10 and −10). If the range difference obtained with these settings is found, the difference which has resulted from a change of 20 units can be divided by 20 to find the change produced by one unit. The same procedure is repeated for objects Y and Z.

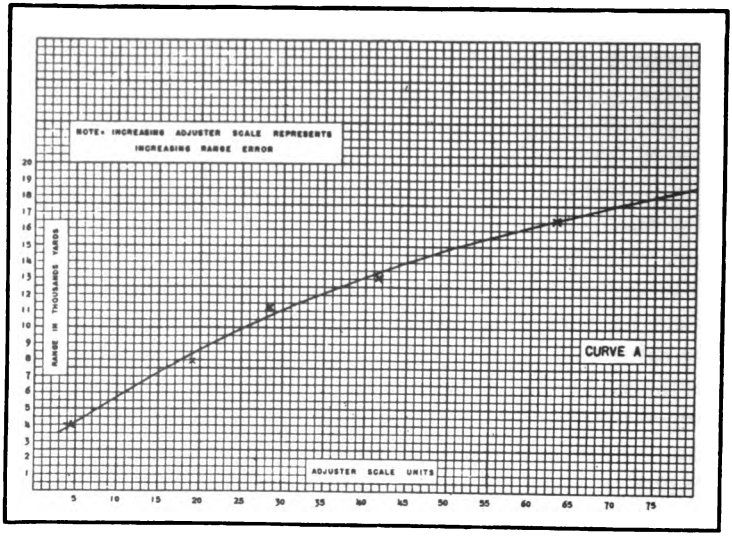

NOTE: INCREASING ADJUSTER SCALE REPRESENTS INCREASING RANGE ERROR
RANGE IN THOUSANDS YARDS
ADJUSTER SCALE UNITS
CURVE A

Figure 14–13.—Typical A-curve.

Digitized by Google

The change in yards that one unit of the adjuster scale will produce for targets X, Y, and A is plotted against the rangefinder range to X, Y, and Z. From the curve drawn through these points the value in yards of one unit of the internal adjuster scale at any range can be determined. (See fig. 14–13.)

Once the A-curve is constructed, if the rangefinder error at a given range is known, it is possible to determine the number of units the internal adjuster scale must be moved to correct for this range error, since the curve gives the change in yards which a change of one unit of the adjuster scale will produce at any range. To make this information readily available for any range, a B-curve, utilizing the data of the A-curve, is prepared. Such a curve is shown in figure 14–14.

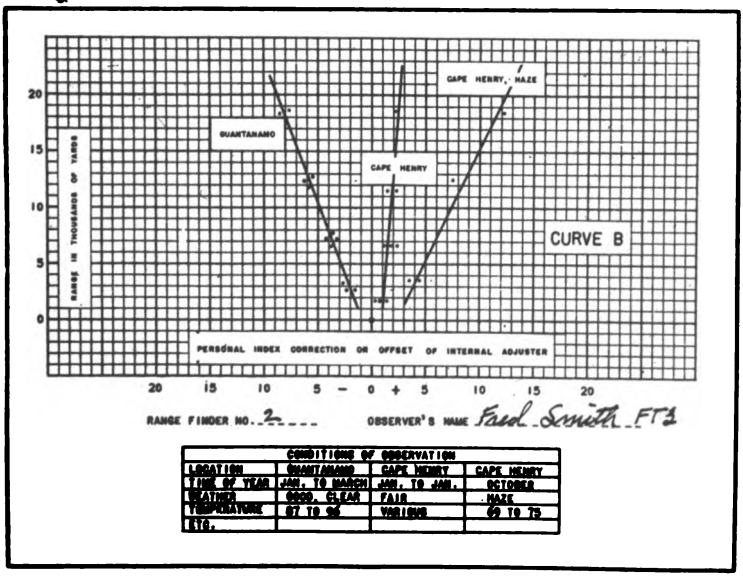

CAPE HENRY, HAZE
GUANTANAMO
CAPE HENRY
CURVE B
RANGE IN THOUSANDS OF YARDS
20
15
10
5
0
PERSONAL INDEX CORRECTION OR OFFSET OF INTERNAL ADJUSTER
20 15 10 5 – 0 + 5 10 15 20
RANGE FINDER NO. 2
OBSERVER'S NAME Fred Smith FT1
CONDITIONS OF OBSERVATION
LOCATION | GUANTANAMO | CAPE HENRY | CAPE HENRY
TIME OF YEAR | JAN. TO MARCH | JAN. TO JAN. | OCTOBER
WEATHER | GOOD, CLEAR | FAIR | HAZE
TEMPERATURE | 67 TO 95 | VARIOUS | 69 TO 75
ETC.

Figure 14–14.—Typical B-curve.

B-CURVE

To construct a B-curve, rangefinder ranges are taken on targets at various ranges, the range of each of which is

Digitized by Google

accurately known. The difference between the measured rangefinder range and the actual range of the target is the range error. Knowing (1) the error in yards, and (2) the value in yards of one unit of adjuster scale from the A-curve, the number of correction units required to make the rangefinder read true range is obtained by dividing (1) by (2). The resultant value plotted against the rangefinder range of the target gives a point on the curve. Several such points are plotted for each B-curve. For accurate results, widely spread ranges are taken on at least three different targets, under various conditions, as shown in the example of figure 14–14. A series of at least 10 ranges is taken on each target, and the readings are recorded and averaged.

The B-curve of figure 14–14 is for one rangefinder operator. It is evident that internal corrections will be different (1) in the same locality under different weather conditions, (2) in different localities, and (3) for each different rangefinder operator. The figure shows corrections for Guantanamo, and for Cape Henry under normal and hazy conditions. Assume that a practice is to be fired in the Cape Henry area under hazy conditions at 15,000 yards. It can be seen that +10 units is the index correction. This means that 10 units should be added to this operator's internal adjustment setting, since the index correction taken from the B-curve should always be applied to the internal adjuster scale setting after the internal adjustment has been made. In practice, after the rangefinder operator has taken an accurate internal adjustment, the optical officer is notified of his scale setting. From the B-curve for the individual operator and the given rangefinder, the optical officer determines the index correction to be applied and notifies the rangefinder operator before he begins ranging. Changes in the index correction which may subsequently be required incident to a change of target, or an appreciable change of the range to the original target, will be sent to the operator by the optical officer.

In all calibrations, the most important consideration is

Digitized by Google

the accurate range to the target. In many localities special rangefinder calibration charts are provided, with suitable targets at various ranges clearly identified. However, there is still the problem of obtaining an accurate position on the chart from own ship. This is done by standard navigational methods. It is to be noted that the anchorage bearings from ship's log are not sufficiently accurate, due to swinging of the ship. Also it must be remembered that if the rangefinder is located at some distance from the bridge, allowance must be made. At long ranges, radar offers an excellent means for determining correct range to check against. Radar range also eliminates the need for checking the position of the ship.

SPOTTING WITH THE RANGEFINDER

The long-base rangefinder is an ideal spotting instrument because you can tell clearly whether the fall of shot is short or over. But to do intelligent spotting it is essential that you understand the unit of error. Here's how it works out: In addition to the ranging mark, the reticles of a rangefinder contain several other marks. Figure 14–15 shows a typical arrangement of one of the reticules.



Figure 14–15.—A rangefinder reticule.

The large diamond in the center is the ranging mark. This large mark is located on the optical axis. The small open diamonds are spaced the same distance from the axis on both reticules. Thus rays coming from corresponding diamonds on the two reticules are parallel to each other, and the diamonds appear to be at the same distance as the ranging mark. The diamonds are spaced so that the angle between

Digitized by Google

them at the eye is five mils. They can therefore be used for spotting a splash in deflection.

Notice the lower pair of solid black diamonds. On the right reticule they are equally spaced about the axis. But, on the left reticule each diamond is shifted slightly to the right. Hence the rays coming to the two eyes from a corresponding diamond on each reticule diverge. The amount of the shift is such that the divergence is 20 minutes ($100 \times 12''$). Therefore, this pair of diamonds will appear to be nearer than the ranging mark by 100 units of error.

Similarly, the next lower pair of black diamonds is 50 units inside the ranging mark. The next pair up is 50 units beyond the mark, and the top pair is 100 units beyond.

Now suppose a splash is seen which appears to be farther away than the lower pair of diamonds, but closer than the next higher pair. You judge that the splash is 75 units short. You still don't know how much to spot. But if the range is 4,000 yards, and if you're using a 15-foot 24X instrument, a unit of error is 7.8 yards. Thus you spot "UP 600."

On some ships the rangefinder operators spot in units of error, and this is converted to yards in plot. But where a spot transmitter calibrated in yards is used, the operator himself must make the conversion mentally and spot in yards.

CARE OF RANGEFINDERS

Rangefinders are delicate instruments requiring very careful handling and operation to produce satisfactory results. Only regular rangefinder personnel should handle them. In cleaning rangefinders, dirt or grit should be removed from optical surfaces with a camel's hair brush to avoid scratching. Use clean lens paper or chamois for wiping the optical parts. Cleaning of lenses with alcohol or ether should be restricted to experienced repair personnel, as both alcohol and ether dissolve the balsam used in cementing the lenses. Any repairs affecting the adjustment of the optical systems of a

Digitized by Google

rangefinder should be accomplished only by qualified optical repair personnel.

Rapid, continuous, and accurate ranging will come only with practice. In taking a range, the range knob should be turned slowly until the target and reticle mark appear to be at the same distance. In doing this, the most accurate ranging is accomplished when the rangefinder is positioned so that the reticle mark appears almost to touch the top of the target. When ranging, if the reticle is moved on the target consistently from one direction, the effect of lost motion will be eliminated in the rangefinder mechanism and a more uniform operator error will be possible. An inexperienced operator may have to pass the target and come back in the other direction before the target and reticle mark appear at the same distance away. Practice in ranging will improve the performance of most operators.

An instrument called a STEREO TRAINER, which is extremely useful in testing and training stereoscopic rangefinder operators, is provided on each large ship and certain shore stations. Smaller ships, such as destroyers, have only one per division.

The tendency to neglect calibration of rangefinders and the training of rangefinder operators, and to place full reliance on radar for ranging should be avoided. Radars are apt to become ineffective at any time because of material failure or jamming. Well-calibrated rangefinders with efficient operators then become the primary method of obtaining range, and must be ready for instant use.

Digitized by Google

QUIZ

1. The trigonometric function used in the triangulation formula for rangefinders is the
   (*a*) sine.
   (*b*) cosine.
   (*c*) tangent.
   (*d*) cotangent.

2. When small angles slightly greater than zero degrees are doubled in size, which one of the following trigonometric functions is also approximately doubled in value?
   (*a*) Secant.
   (*b*) Cosine.
   (*c*) Tangent.
   (*d*) Cotangent.

3. The parallactic angle θ is equal to
   (*a*) $206{,}265 \frac{BM}{R}$.
   (*b*) $206{,}265 \frac{BR}{M}$.
   (*c*) $206{,}265 \frac{MR}{B}$.
   (*d*) $B \frac{MR}{206{,}265}$.

4. If the base length between your eye pupils is increased from 2.5 inches to 20 ft., your ability to detect distance will be increased by approximately
   (*a*) 65 times.
   (*b*) 75 times
   (*c*) 85 times.
   (*d*) 95 times.

5. The addition of telescopes in the two halves of a rangefinder increases the range sensitivity by an amount proportional to
   (*a*) their magnifying power.
   (*b*) ½ their magnifying power.
   (*c*) ¼ their magnifying power.
   (*d*) ⅛ their magnifying power.

6. A second rotating prism or wedge in tandem with the measuring wedge
   (*a*) decreases the refractive power.
   (*b*) cancels the vertical refraction.
   (*c*) compensates for the distertion of the image.
   (*e*) holds the range sensitivity constant.

Digitized by Google

7. The main reason why the end glass ports of a rangefinder should not be moved by ship's personnel is because
   (*a*) they are fragile and break easily.
   (*b*) the gas seal will break.
   (*c*) the glass is polarized.
   (*d*) the glass is slightly wedge shaped, forming a prism.
8. The inter-pupillary distance adjustment is accomplished by rotating two
   (*a*) triangular prisms.
   (*b*) penta prisms.
   (*c*) rotating prisms.
   (*d*) rhomboid prisms.
9. The height adjuster consists of a glass disk having surfaces which are
   (*a*) convex, convex.
   (*b*) convex, concave.
   (*c*) plano, concave.
   (*d*) parallel.
10. The rangefinder height adjustment is made by sighting on a vertical edge of a distant target
   (*a*) through first one port and then the other.
   (*b*) through one eye at a time.
   (*c*) by alternately tilting your head each way.
   (*d*) from two different angles.
11. The internal adjustment of the rangefinder is made by positioning the
   (*a*) range wedge.
   (*b*) left adjuster penta prism.
   (*c*) correction wedge.
   (*d*) left adjuster objective lens.
12. The internal adjuster scale is calibrated in
   (*a*) seconds.
   (*b*) minutes.
   (*c*) mils.
   (*d*) arbitrary units.
13. The stereo-acuity of the average rangefinder operator is about
   (*a*) 6 seconds.
   (*b*) 8 seconds.
   (*c*) 10 seconds.
   (*d*) 12 seconds.
14. The formula for unit of error, *e*, is calculated in terms of
   (*a*) yards.
   (*b*) mils.
   (*c*) seconds.
   (*d*) arbitrary units.

Digitized by Google

15. The variance of the unit of error is proportional to range
    (*a*) doubled.
    (*b*) squared.
    (*c*) tripled.
    (*d*) cubed.
16. When the base length of a rangefinder is doubled, the unit of error is
    (*a*) quartered.
    (*b*) reduced to a third.
    (*c*) halved.
    (*d*) 58.2 percent.
17. When the magnifying power of the optical system of a rangefinder is reduced to one-half of the original value, the unit of error is
    (*a*) doubled.
    (*b*) squared.
    (*c*) tripled.
    (*d*) cubed
18. From the following data, compute the unit of error and choose the best rangefinder operator.
    (*a*) Jones (15-ft 24X rangefinder) : range 10,000, error 250.
    (*b*) Patrick (12-ft 25X rangefinder) : range 16,000, error 600.
    (*c*) Smith (18-ft 15X rangefinder) : range 20,000, error 800.
    (*d*) Blake (30-ft 12X rangefinder) : range 35,000, error 1200.
19. The A-curve is plotted in terms of
    (*a*) unit of error.
    (*b*) units of adjuster scale.
    (*c*) units of range scale.
    (*d*) stereo-acuity units.
20. A B-curve is plotted from range errors divided by
    (*a*) unit of error.
    (*b*) units of adjuster scale.
    (*c*) units of range scale.
    (*d*) stero-acuity units.

Digitized by Google

CHAPTER 15

TORPEDO FIRE CONTROL

With the present day emphasis on guided missiles, rockets, and automatic weapons the Fire Control Technician is apt to forget the importance of the torpedo and the associated torpedo fire control instruments. The torpedo, nevertheless, remains a potent enemy of the surface vessel. The tonnages sent to the bottom by these "tinfish" are staggering: 11,000,000 tons of allied shipping in World War I and 6,000,000 tons of Japanese shipping in World War II.

In spite of this impressive record, many Fire Control Technicians assigned to destroyers are apt to slight the torpedo firing installation as being the sole responsibility of the Torpedoman. However, the qualifications listed in the appendix specifically describe the duties and responsibilities of the Chief Fire Control Technician or leading Fire Control Technician as follows: THE CHIEF ORGANIZES, SUPERVISES, AND PERFORMS MAINTENANCE AND REPAIRS OF ALL FIRE CONTROL EQUIPMENT ABOARD SHIP.

If you, therefore, are to meet the qualifications for advancement in rating as outlined in appendix II of this manual, and, perhaps more important, are to teach personnel the proper operation and maintenance of the torpedo director, it is necessary that you have a thorough knowledge of the torpedo fire control problem.

The gun fire control problem is usually introduced by a discussion of the characteristics of a projectile in flight.

Digitized by Google

The torpedo fire control problem, likewise, is best introduced by a brief explanation of a torpedo and an analysis of its run.

THE TORPEDO

Torpedoes are self-propelled weapons designed to carry a large charge of high explosives to a target. Driven through the water by gas and steam, chemicals, or by electricity, they can be controlled to run over a fixed course at a constant speed and at a set depth. While submarine or destroyer torpedoes are usually 21 inches in diameter and 21 feet in length, those launched from aircraft or PT boats are 13½ feet long and 22½ inches in diameter.

Speeds of torpedoes vary between 27 and 47 knots, and their ranges from 4,000 to 16,000 yards. High speed torpedoes are preferable, naturally, since they allow the target less time to maneuver. But the range to the target also enters the argument. The energy required for propulsion increases rapidly as the speed increases. Therefore the distance a torpedo can travel depends on its speed. Consequently there are torpedoes of one, two, and three speeds in use, thus permitting speed selections for different firing conditions.

The modern torpedo, whether driven by chemicals, electricity, or by gas and steam, has four major sections as shown in figure 15–1.

1. The HEAD. It may be a warhead containing explosive, or an exercise head used for practice shots.
2. The AIR-FLASK OR BATTERY COMPARTMENT. This section contains the potential energy required for propulsion and control. This part also contains the piping and valves needed to release the energy.
3. The AFTERBODY. This is the engine room of a torpedo, housing nearly all components of the propelling, depth, and steering mechanisms.
4. The TAIL. It supports the stabilizing vanes, propellers, and rudders.

Digitized by Google

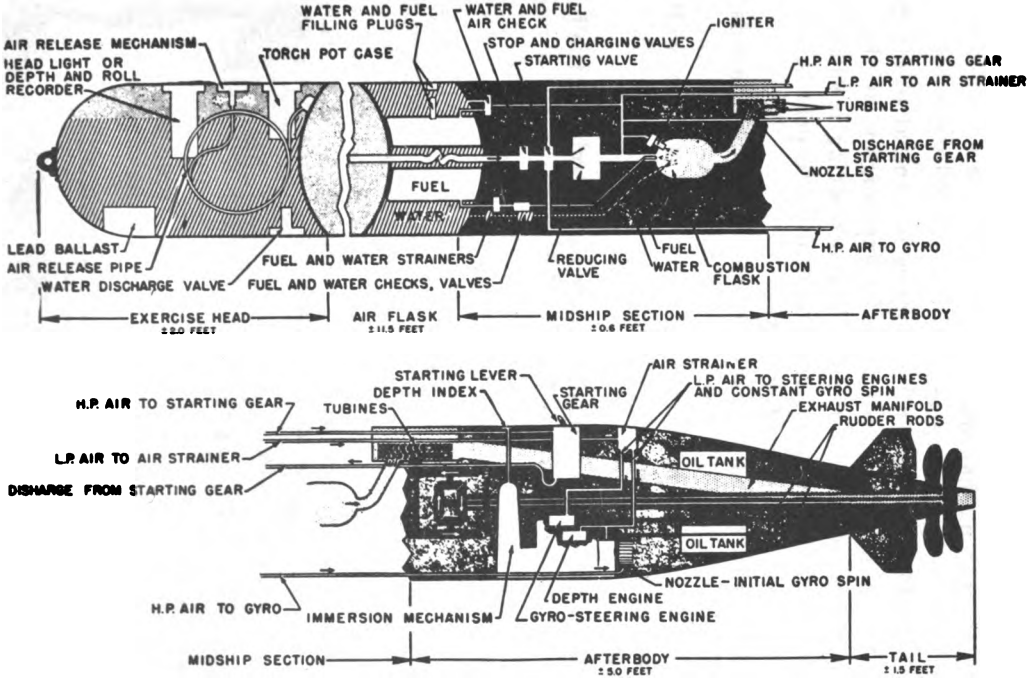


Figure 15–1.—Schematic of a torpedo with an exercise head in place.

Digitized by Google

All war torpedoes must have:

1. An explosive charge.
2. An energy supply for operation.
3. A propelling mechanism.
4. A depth mechanism.
5. A steering mechanism.

The following description applies in general to all gas- and steam-driven torpedoes. The explanation of the explosive charge, and of the depth and steering mechanisms are also applicable to electric and chemical torpedoes, which have different sources of energy.

The explosive charge, varying from 400 to 800 pounds, is TNT, a mixture of TNT and torpex, or HBX–1 cast into the warhead as shown in figure 15–2. The head is a thin-walled container strengthened by ribs and the solidity of the charge itself.

The exploder mechanism is housed in a cavity at the bottom of the warhead. It has the functions of (1) arming the exploder during the first part of the run, and (2) detonating the main charge upon impact.

Practice firings required to test torpedoes and train personnel are conducted with exercise heads which look similar

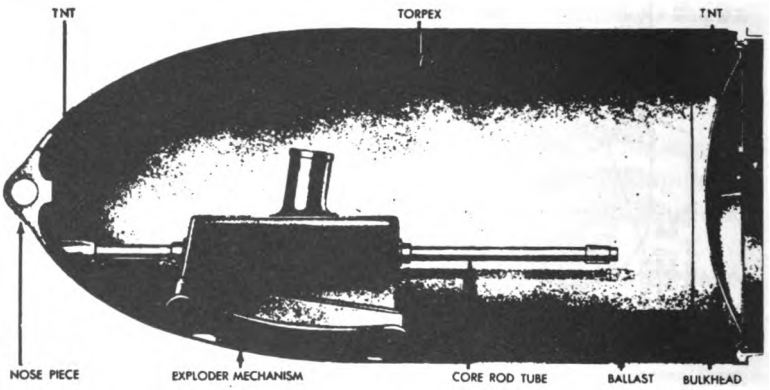


Figure 15–2.—Cutaway view of a torpedo war head.

Digitized by Google

to the one shown in figure 15–1. They have the same dimensions as warheads, and are filled with a ballast solution of calcium chloride and water to give them the same trim characteristics as warheads. The solution is automatically expelled by air from the air flask at the end of the run, so that the torpedo will rise to the surface. A torch pot is carried in the exercise head to produce smoke which will serve to guide the recovery crew.

The energy needed to propel and control the torpedo is stored in the air flask. The larger forward part of the flask is charged with compressed air at 2,800 pounds per square inch pressure. Within the small compartment at the rear of the air flask is a tank containing alcohol. The space surrounding the tank is filled with water. The air, alcohol, and water are led to valves in the midship section.

When the starting lever, shown in figure 15–1, is tripped at launching, a starting valve opens. A small part of the air is used at high pressure in the starting and steering mechanisms. The rest of the air is throttled to a pressure of about 450 p.s.i. and goes to the fuel and water tanks, the combustion flask and the depth and steering mechanisms.

The air admitted to the fuel and water tanks forces the liquids through separate pipes to the combustion flask in figure 15–1. At the same time, an igniter in the combustion flask is fired by means of two firing pins actuated by compressed air. The alcohol is mixed with air, and the mixture enters the top of the combustion flask, where it is ignited by the burning primer. The burning material is transformed to hot gases into which water is sprayed. The resulting mixture of gas and steam is led to the propelling mechanism.

The gas-steam mixture from the combination flask is directed through nozzles against the blades of balanced turbines in the main engine (fig. 15–1). The turbines revolve in opposite directions, and are connected by gears and shafts to the two propellers. The propellers, of opposite pitch, also revolve in opposite directions and drive the torpedo through the water.

Digitized by Google

The depth at which the torpedo runs is controlled by the depth mechanism located in the afterbody. The mechanism (fig. 15–3) contains a spring loaded diaphragm which is actuated by the pressure of the sea water, and by the pendulum. The diaphragm and the pendulum are interconnected and, by a system of linkages, control a valve which in turn causes the depth engine to move the rudders. The depth of run is set by adjusting the tension of the diaphragm spring before the torpedo is launched.

Let's assume that the torpedo is below its set depth, with its axis horizontal. The pressure of the water will force the diaphragm down against the action of the spring and the trapped air, as shown in the up-rudder schematic of figure 15–3A. This movement rotates the pendulum lever counterclockwise, moving the link, pendulum and valve to the left. The piston following the valve applies up-rudder.

As the torpedo begins to incline upward, gravity tends to pull the pendulum down to the right (fig. 15–3A) against

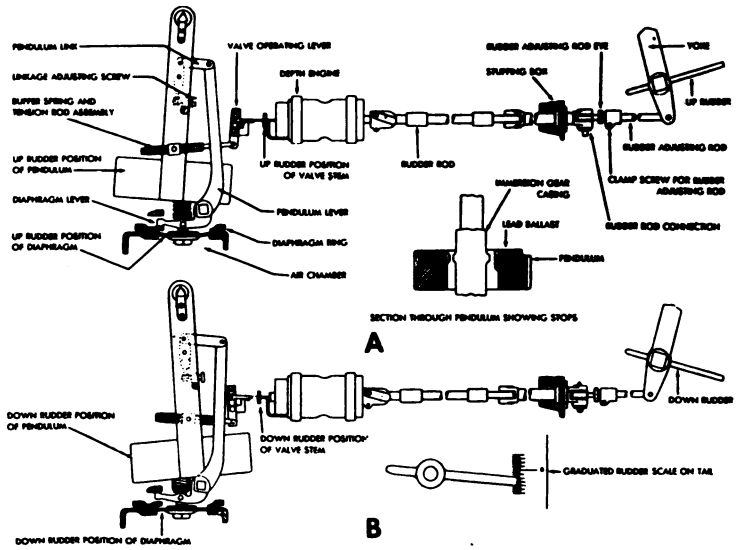


Figure 15–3.—Diagrammatic view of a torpedo depth mechanism.

Digitized by Google

the action of the diaphragm. This results in a reduction in the amount of up-rudder. When the torpedo inclines enough to cause the pendulum action to just balance the diaphragm action, the rudders will be in neutral, but the torpedo will be climbing.

As the torpedo climbs, the diaphragm action decreases, and the pendulum moves farther to the right, applying down-rudder. This causes the torpedo to begin levelling off, and it arrives at its set depth at a slow rate of climb.

Action is similar (fig. 15–3B) when the torpedo is running above its set depth, except that at first the control causes down-rudder. The pendulum thus tends to eliminate overshooting, and the torpedo runs at a fairly uniform depth that is established by the tension set in the spring before the run.

The Torpedo Steering Mechanism

The course a torpedo steers after launching is controlled by a steering mechanism contained in the afterbody. It consists of a gyroscope, linkage, and steering engine. At the moment of launching, a blast of high-pressure air spins the gyroscope as shown in figure 15–1, and from then on low-pressure air keeps it spinning.

Throughout the run of the torpedo the gyroscope maintains its axis of spin parallel to its original position. Variations in the angle between the axis of spin and the axis of the torpedo are transmitted by the linkage to the valve of the steering engine. The steering engine is shown removed from a torpedo in figure 15–4. The steering engine steers the torpedo so that the angle between the two axes remains constant at the value set before the torpedo was launched. The gyro can also be set to cause the torpedo to turn through an angle before it takes up its fixed course.

The gyro of the torpedo exhibits the same characteristics as all gyros; namely, precession, and the rigidity of the plane of rotation. As you know, rigidity of the plane of rotation in space means that the gyro spin axis will appear to move, due to the earth's rotation. Now the function of the steering

Digitized by Google

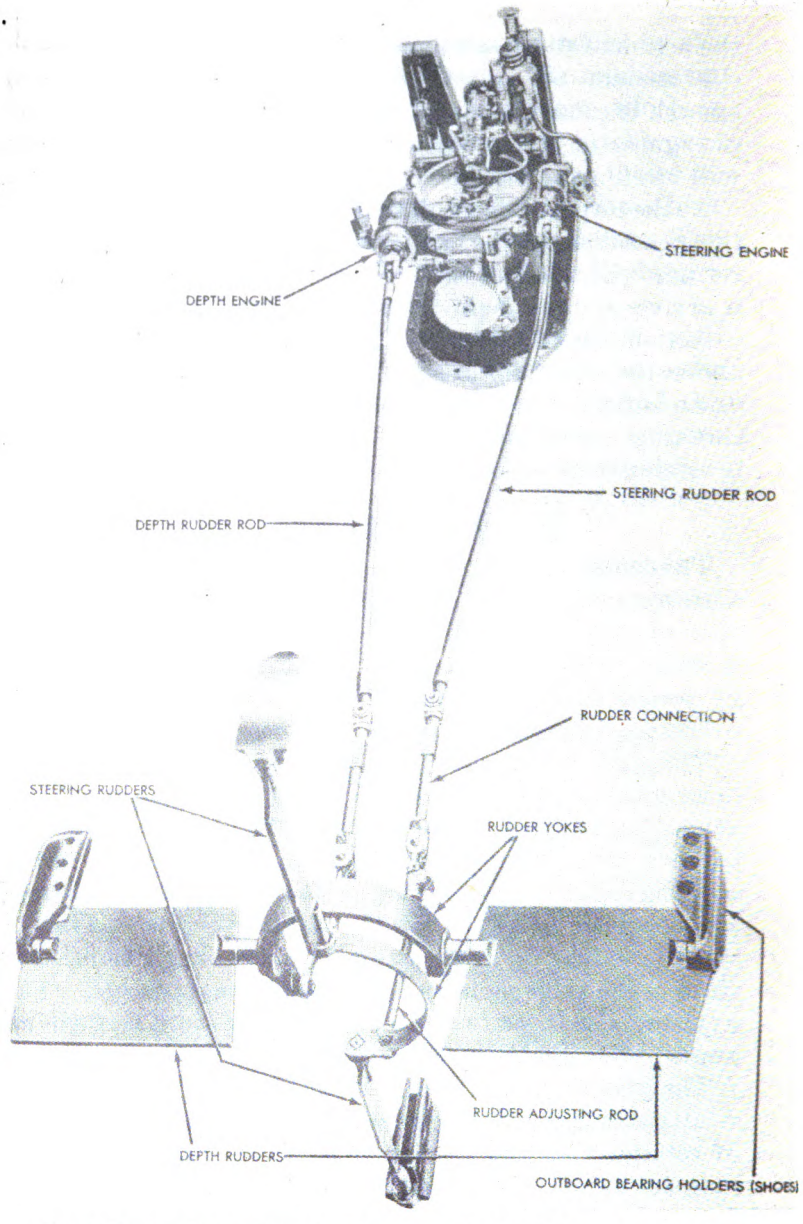


Figure 15–4.—Gyro and depth mechanisms, showing linkage to depth and steering rudders.

Digitized by Google

engine is to maintain a definite angular relationship between the longitudinal axis of the torpedo and the spin axis of the gyro. The torpedo, therefore, will appear to drift from a straight-line course by an amount proportional to the rotation of the earth during the running time of the torpedo.

In other words, the torpedo is maintaining a straight-line course in space. But as seen by an observer on the earth, it is apparently running on a CURVED COURSE away from the EARTH'S LINE OF FIRE.

This curve of the torpedo's path away from the earth's line of fire is recognized as CREEP. The amount and direction of creep vary according to the firing latitude and the time of the torpedo run. In north latitudes the creep is always to the RIGHT of the observer's line of sight (assuming that we have a static balanced gyro); and conversely, in south latitudes creep is always to the LEFT. Along the equator, of course, there is no creep since apparent rotation of the gyro is a function of the sine of the latitude angle. The sine of 0° is zero.

Latitude Correction

Since it is desirable that a torpedo run a straight course, the gyro is equipped with a balance nut (latitude correction weight). The position of the nut, which is calibrated in turns, corresponds to the latitude setting.

If the balance nut is set for the firing latitude the torpedo will run a straight course. If the torpedo is fired in any other latitude, however, it will creep by an amount proportional to a function of the difference between the latitude setting of the balance nut and the firing latitude.

When the torpedo is issued to the fleet the balance nut is usually set at static balance, which is 1.5 turns. Static balance is the setting for latitude 0°. After the torpedo is received aboard ship it is the responsibility of the Torpedoman to change the latitude setting with each change in ship's latitude. It is not always practicable, however, to set the balance nut before firing. For this reason provision must be

Digitized by Google

made to introduce into the torpedo director a compensation for creep. This correction is determined from the following formulas:

$$Kla = \frac{0.0037 \times R \times (\sin L2 - \sin L1)}{Sto} \quad (1)$$

$$Kla = \frac{0.0037 \times R \times (\sin L2 + \sin L1)}{Sto}. \quad (2)$$

Where:

Kla is the latitude correction in degrees.

0.0037 is a constant.

R is the torpedo run in yards.

*L*2 is the firing latitude.

*L*1 is the balance latitude.

Sto is the torpedo speed in knots.

When *L*2 and *L*1 are on the same side of the equator, formula (1) applies; and when they are on opposite sides of the equator, formula (2) applies.

There is a more simple and rapid means of determining this latitude correction in degrees. The graphs shown in figures 15–5 and 15–6 can be used to calculate this setting. The practical use of the curves is simple.

From the curves in figure 15–5 pick off the difference between the balance nut setting for the FIRING LATITUDE and for the BALANCE NUT LATITUDE. Be sure to use the curve that represents the correct gyro speed. With this balance nut difference as the ordinate of the curves of figure 15–6, move your finger horizontally to the curve representing the correct gyro r. p. m. Then drop vertically downward from this point and read the corresponding abscissa which gives the amount the torpedo tube (or director) must be indexed (trained) per minute of torpedo run. Now multiply the amount of index by the estimated number of minutes of torpedo run. The answer will be the total amount the tube will have to be indexed from the original line of fire in order to hit the target. If the difference between the ACTUAL BALANCE NUT POSITION (as set on the gyro) and the FIRING LATITUDE NUT POSITION is positive, the tube must be indexed

Digitized by Google

to the right. If the difference is negative, the tube must be indexed to the left. This rule of thumb holds true for all latitudes.

As an example, assume that a ship at the equator wants to fire a torpedo which has a balance nut setting corresponding to latitude 41° N., and which has a 10,000 r. p. m. gyro. Its balance nut, therefore, is set at 1.9 turns. From the middle curve of figure 15–5 we find that the difference in balance nut settings between the two latitudes is plus 0.4 turn. Now

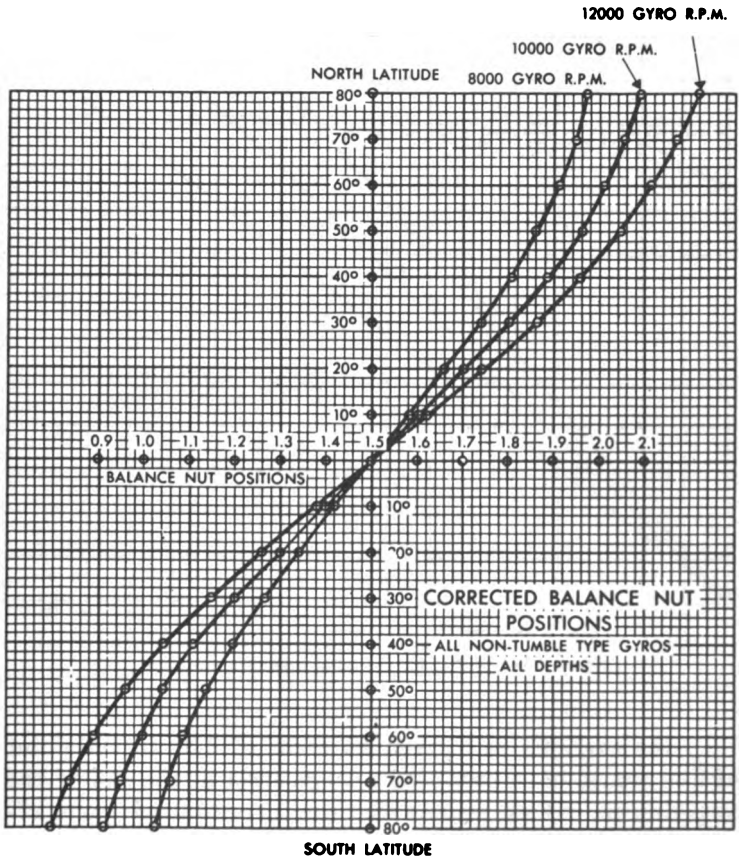


Figure 15–5.—Corrected balance nut positions.

Digitized by Google

turn to figure 15–6, and with an ordinate of 0.4 turn, move horizontally to the 10,000 r. p. m. curve and drop vertically downward, reading the abscissa as 0.084, thus obtaining the amount the tube must be indexed (in degrees) per minute of torpedo run. If we now estimate that the torpedo will have to run for 15.5 minutes before it strikes the target, we will have to index the tube an amount equal to 15.5 times 0.084 or 1.3°. Since the balance nut difference was PLUS 0.4 turn, the tube will have to be indexed to the RIGHT an amount equal to 1.3°.

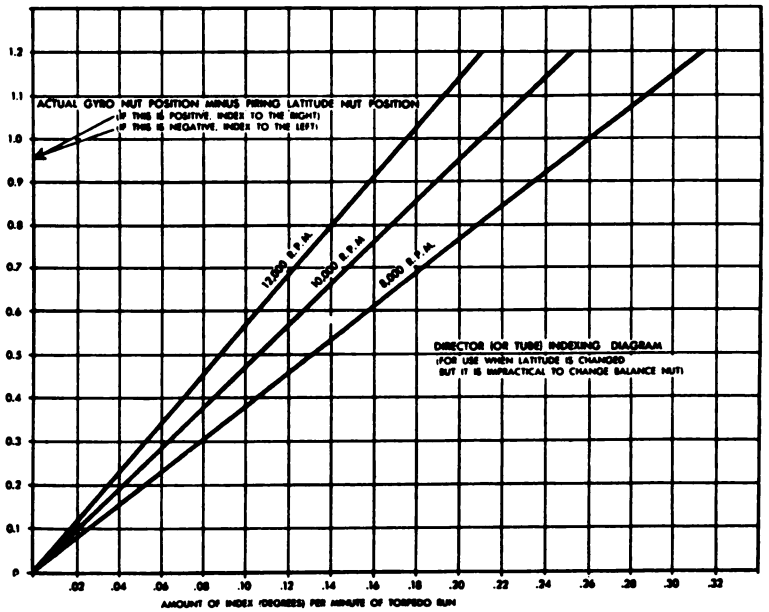


Figure 15–6.—Director (or tube) indexing diagram.

In the example just given an error of 1.3° in the point of aim would have produced a large error at the end of the torpedo run. If we assume that the torpedo fired was a 27-knot torpedo, the deflection error at the target would have been approximately 300 yards.

Digitized by Google

To one who doesn't work with torpedoes every day, the electric torpedo looks very similar to the air-steam torpedo. The most prevalent electric torpedo is the Mk 18. It is the same size as the air-steam torpedo, and can be fired from the same tube. It weighs 1.5 tons and carries 595 pounds of HBX in its war head.

Since the electric torpedo does not leave a wake, it is used by submarines, thus enabling the sub to keep her position from being easily detected. Because of its slower speed of 29 knots, the electric torpedo is not fired from surface vessels; also, it is not built ruggedly enough to take the jolt when it hits the water after being fired from an above-water tube.

The Mk 18 is propelled by a series d-c motor which develops 1 hp at 1,660 r. p. m. Electric energy is furnished to the motor from 72 lead-acid battery cells connected to give 168 to 172 volts.

The battery compartment is sealed from the afterbody by a bulkhead in order to restrict the hydrogen given off from the batteries. Otherwise an explosion set off by motor sparks could occur. To further guard against an explosion, an electric hydrogen burner is installed in the battery compartment. Air from the afterbody is allowed to enter the battery compartment to sustain the burning of the hydrogen.

Like the air-steam torpedo, the gyro and the steering engine are powered by compressed air. The compressed air comes from three small flasks in the afterbody.

In the first second after the torpedo is fired, high-pressure air supplied from the flasks brings the gyro up to full speed. Air from the gyro spinning mechanism exhausts into the afterbody. Also, throughout the torpedo run, the depth and steering engines use air from the flasks which, after use, also exhausts into the afterbody; the air pressure is transformed by a reducing valve.

Thus the air pressure in the afterbody gradually increases.

Digitized by Google

To keep it from building up too high, some of the air is let into the battery compartment. As previously mentioned, this air is required to burn hydrogen. But, at the same time, we have to prevent air from moving in the opposite direction through the gas-tight bulkhead which isolates the battery compartment. A poppet valve takes care of this. It has a threaded body which screws into the after side of the battery compartment bulkhead. The poppet is simply a one way, spring loaded valve. When the air pressure in the afterbody builds up to a certain value—the spring is overcome, the valve opens, and air passes into the battery compartment. Then, when the pressure lowers sufficiently, the spring forces the poppet valve to close.

Although different in a few respects, the details of the depth mechanism of the electric torpedo are so much like those for the depth mechanism of the air-steam torpedo that no further discussion will be included here.

The torpedo fire control problem for submarines is enough like the surface torpedo problem that no additional discussion on it will be included, either.

TORPEDO F. C. PROBLEM

Now that you have examined the construction of a torpedo we shall proceed with the fire-control problem used by destroyer torpedo directors. Let us first consider what data of a torpedo run will affect the fire control problem:

1. The torpedo travels at a constant velocity.
2. The torpedo will creep (drift) from the earth's line of fire unless the balance nut on the gyro is set for the firing latitude.
3. The torpedo's run is not affected to any measurable extent by the motion of own ship. Therefore, the motion of own ship can be neglected.
4. The torpedo gyro can be set to cause the torpedo to turn through an angle before it takes up a fixed course as shown in figure 15–7. Notice in the diagram that the torpedo travels straight for a short distance after

Digitized by Google

it emerges from the tube. Then it begins to curve through an arc, the length of which depends upon the gyro angle. Finally it takes up a straight course which brings it to the point of intercept with the target. The angle between the MEAN TORPEDO COURSE *Bto* and TUBE TRAIN *Btu* is known as BASIC GYRO ANGLE, *Bgy*. It is measured clockwise from tube train as shown.

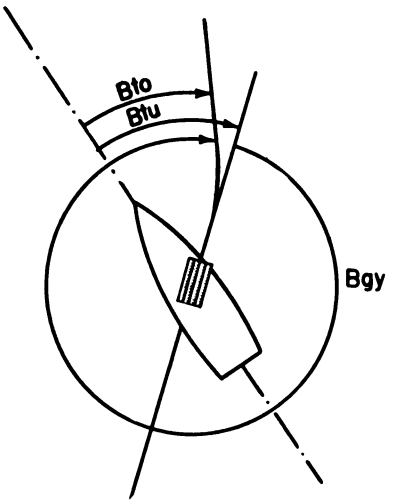


Figure 15–7.—Basic gyro angle.

The Destroyer Torpedo Problem

Basically the torpedo fire control problem resolves itself into the simple question: how much do you lead the target in order to get a hit? Of course, you assume that the target will be within the limited range of the torpedo at the time of collision.

Since the torpedo is a constant velocity projectile, the time of run varies directly with range. The effect of own ship's motion on the torpedo is so small that it can be neglected. The problem, therefore, resolves itself into a triangle (fig. 15–8) formed by the following sides: target

Digitized by Google

run in yards, torpedo run in yards, and the line of sight. Looking at figure 15–8, we see:

1. *Bs* is relative target bearing.
2. *Bt* is target angle (obtained from the conventional formula $Bt=B+180°-Ct$).
3. *Bto* is basic torpedo course (the angle measured clockwise from bow of firing ship to mean torpedo track).
4. *Btr* is track angle, the angle at the point of intercept measured from bow of target to torpedo track. (The ideal track angle is usually considered to be 90° or 270°, because under such conditions the target ship is squarely broadside when the torpedo arrives.)
5. *Ds* is basic sight angle.

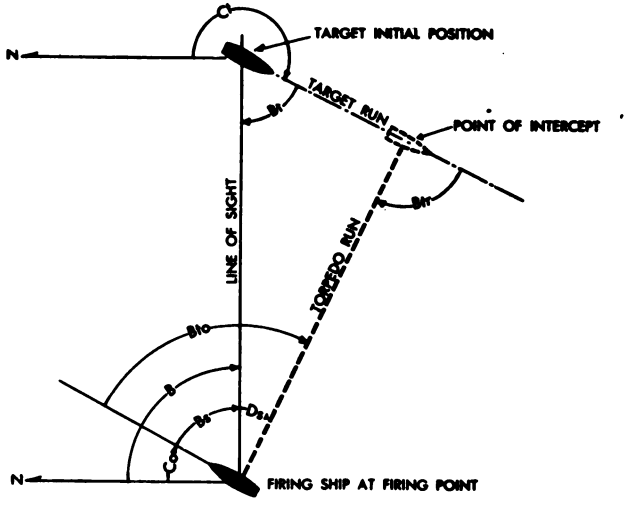


Figure 15–8.—The basic range triangle of the torpedo fire control problem.

The problem in figure 15–8 would be difficult to solve for *Ds*. There is a basic concept derived from your study of vectors, however, which will simplify it.

As you remember, a vector is a graphical presentation of any quantity which has both magnitude and direction. We can use vectors to represent the speed and course of a ship—or the speed and course of a torpedo.

Digitized by Google

If time is considered as unity, a vector—besides representing course and speed—can also equal range. For example, imagine a vector showing the course (0°) and speed (20 knots) of a ship. Now if we assume time to be one hour, the length of the vector also equals 20 knots times 2,026 yards or 40,520 yards.

Figure 15–8 shows that the time of the target run, and the time of torpedo run must be equal to score a hit. If we consider this mutual value of time as unity, we can replace the distance triangle of figure 15–8 with the vector triangle of figure 15–9. The vectors of figure 15–9 therefore represent the course and speed of the torpedo, and target course and speed. Range drops out of the problem.

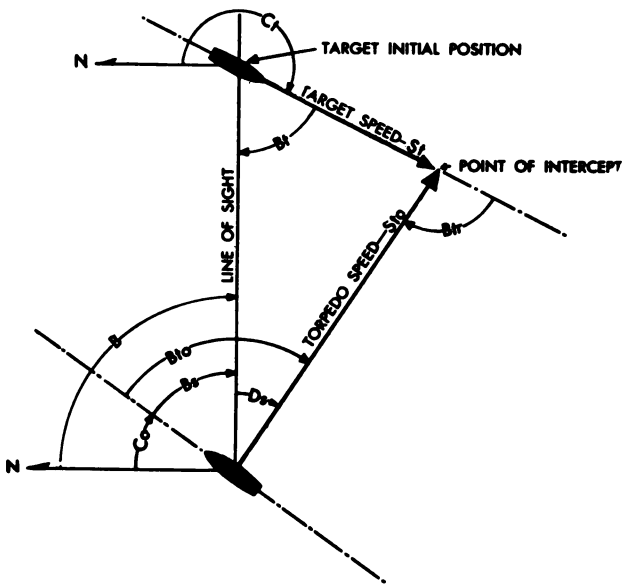


Figure 15–9.—The basic vector triangle of the torpedo fire control problem.

All the quantities in figure 15–9 with the exception of D_s are known or can be found. Target course and speed are usually furnished by CIC; however, they may be furnished by plot if the director is tracking the same target. Target

Digitized by Google

angle *Bt* is derived from target course. The torpedo director establishes the line of sight. Torpedo speed *Sto* is known. The basic sight angle *Ds* must be calculated.

The vectors of torpedo course and speed, and target course and speed can each be resolved into two components—a deflection component at right angles to the line of sight (fig. 15–10A), and a range component along the line of sight.

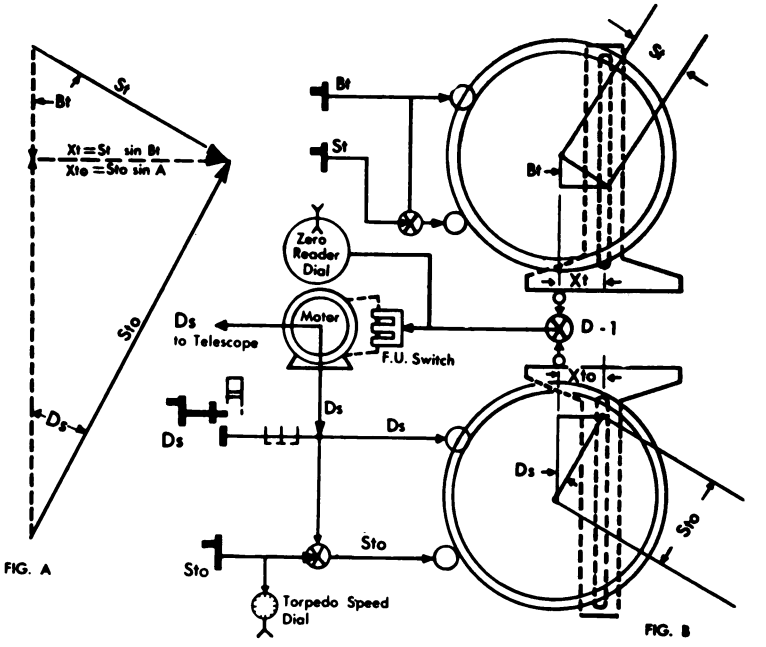


Figure 15–10.—The solution of the triangle of torpedo fire.

Notice that the horizontal deflection components of both vectors are equal. *Xt* must equal *Xto*, because they are the common side of the two right triangles contained in figure 15–10A.

Knowing *St*, *Bt*, and *Sto*, the basic torpedo problem becomes easy. From figure 15–10A, since *Xto* equals *Xt*,

Digitized by Google

$$Sto \sin Ds = St \sin Bt.$$

$$\text{Therefore, } Ds = \text{arc sin } \frac{St \sin Bt}{Sto}.$$

This equation can be solved by two component solvers. Since range has been eliminated from the problem, only the SINE racks are required.

The solution of the problem by these component solvers of figure 15–10B is practically self-explanatory. The three known quantities, *Bt*, *St*, and *Sto* are set in by their respective hand cranks or servo follow-ups. As *Bt* and *St* are cranked in, the movement of the sine rack of the target ship (or upper) component solver is transmitted through D–1 to offset the zero reader dial. A solution to the problem is reached when the *Ds* handcrank or follow-up turns its angle gear until the output—*Xto*—drives through D–1 to synchronize the zero reader dial. When the zero reader dial is synchronized *Xto*=*Xt*. As *Ds* turns the angle gear it also offsets the telescope of the director through the angle *Ds*.

Basic sight angle, however, seldom positions the telescope directly because corrections to sight angle are introduced, and *Ds* becomes *Dsk*, the CORRECTED SIGHT ANGLE.

Corrections to Basic Sight Angle

Corrected sight angle is obtained by modifying *Ds* with LATITUDE CORRECTION *Kla* and INTERCEPT OFFSET *Osi*. Latitude correction is a correction in degrees to *Ds*. But intercept offset is not so clearly defined. It might be called a last minute correction to sight angle based on your estimate of target maneuvers during the torpedo's run. It is defined as an arbitrary change in sight angle such that the point of intercept is moved from its computed position through an angle measured to the right or left of computed torpedo track.

Notice that both quantities are set into the *Ds* line through D–2 (fig. 15–11B). Latitude correction is read against the

Digitized by Google

outer fixed index, while intercept offset is read against the index on the latitude correction dial.

Kla moves the outer dial only. Latitude correction, therefore, must be introduced indirectly. It is not until the intercept offset dial is matched with the index on the inner edge of the latitude correction dial that *Kla* changes *Ds*. The dials as shown read latitude 2° S. correction, and 0° intercept offset.

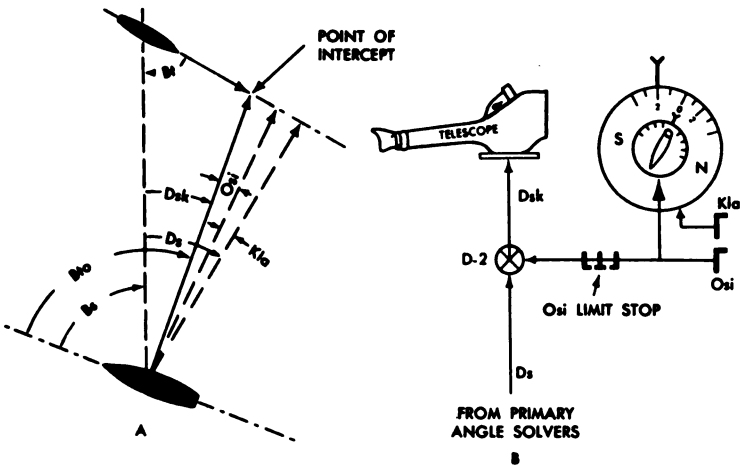


Figure 15–11.—Corrections to basic sight angle.

If basic sight angle is modified by both *Kla* and *Osi* the problem becomes that of figure 15–11A. Basic sight angle is now CORRECTED SIGHT ANGLE *Dsk*. Now that *Dsk* is computed, the determination of BASIC TORPEDO COURSE *Bto*, is a simple matter.

Basic Torpedo Course

Basic torpedo course is the sum of two components (fig. 15–11A), (1) relative target bearing *Bs* and (2) corrected sight angle *Dsk*. In actual operation the pointer at the director keeps the telescope on the target, thus maintaining rela-

Digitized by Google

tive target bearing. The director is so constructed that *Dsk* offsets the telescope from the center line of the director by an amount equal to corrected sight angle. The position of the director case, unless changed by tube offset, is therefore basic torpedo course *Bto*. Basic torpedo course is transmitted to the torpedo mount as BASIC TUBE TRAIN *Btu*.

Basic torpedo course, however, is seldom used with a single torpedo in destroyer fire. Destroyers are usually seen by target ships in the early stages of attacks, and therefore their torpedoes must be fired at comparatively long ranges. Thus the target has time to maneuver to avoid being hit. For this reason, destroyers generally fire several torpedoes in a spread rather than a single torpedo along the basic torpedo course. Such a procedure greatly increases the chances of getting a hit.

METHODS OF FIRING

On ships having movable tube mounts, the two firing methods usually employed to achieve a spread are,

1. STRAIGHT FIRE WITH SPREAD GYRO ANGLES, and
2. CURVED FIRE WITH SPREAD GYRO ANGLES.

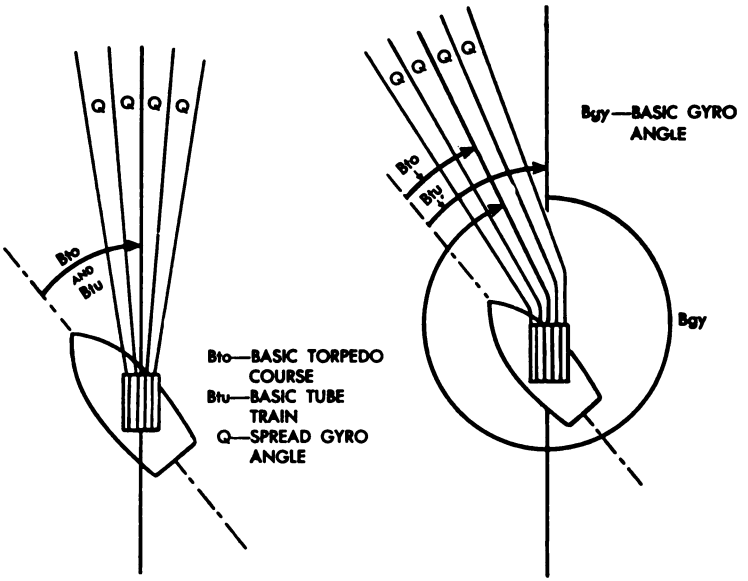
Both methods are shown in figure 15–12.

Figure 15–12A shows straight fire with spread gyro angles from a quintuple tube mount. The torpedo problem is solved by the director, and the mount is trained by matching pointers as the tube train indicator on the mount. The basic torpedo course—the heavy centerline—is parallel to the tube axis and is identical to basic tube train. The spread is produced by gyro angle settings. These settings differ from zero only by an amount necessary to produce the desired spread. This amount, usually specified by torpedo-firing doctrine, is called SPREAD GYRO ANGLE and is indicated by the letter *Q*.

Notice that in straight fire with spread gyro angles the center-tube is fired with zero gyro angle.

Figure 15–12B shows curved fire with spread gyro angle.

Digitized by Google



A. STRAIGHT FIRE WITH SPREAD B. CURVED FIRE WITH SPREAD

Figure 15–12.—Methods of torpedo fire with movable tube mounts.

Curved fire is usually controlled from the torpedo director also. A BASIC GYRO ANGLE *Bgy* is used to make the torpedoes curve between the time they leave the tubes and straighten out on their final courses. The basic gyro angle may be combined with spread gyro angle to produce a spread. The torpedoes curve through the set gyro angle after they are in the water, and straighten out on courses which differ from the tube axis by the amount of the gyro angles.

With ships fitted with fixed tubes, or where movable tube mounts are clamped into place, two other firing methods are often employed:

1. The firing course method, and
2. Curved fire ahead.

The torpedo director is used to solve the problem in the firing course method. The tube mounts are trained and clamped at any safe launching angle. Having determined

Digitized by Google

the correct torpedo course, the ship is swung until the tubes are correctly positioned for firing. Spread gyro settings may be set into the torpedoes, or the required spread may be obtained by swinging the ship. Normally, the required angles are set into the torpedo gyros.

Curved fire ahead with spread is shown in figure 15–13. This method was formerly used when both port and starboard batteries were to be fired at the same target. It is shown here, not as a typical form of firing, but as a demonstration of the problems of pattern firing.

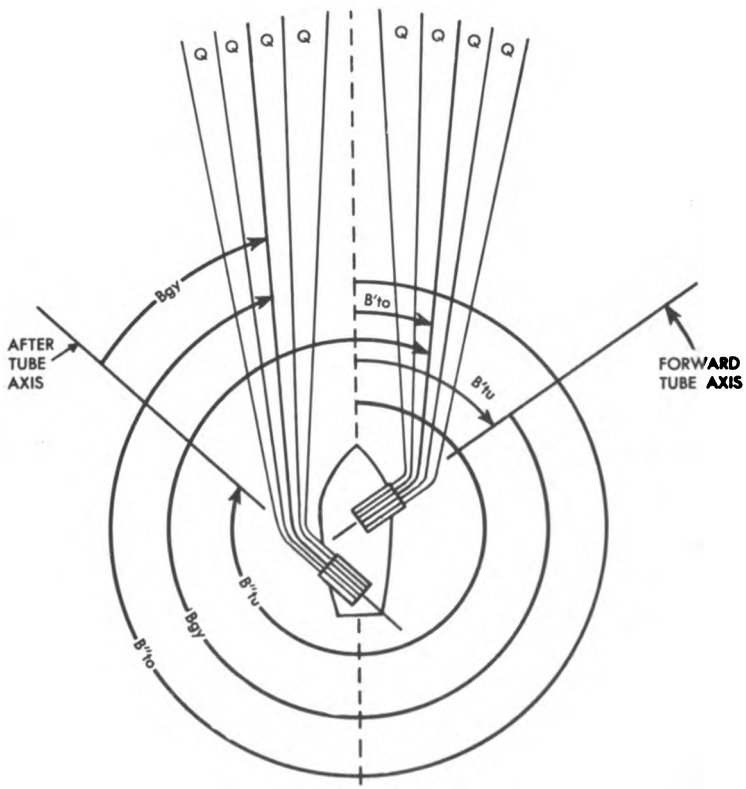


Figure 15–13.—Curved fire ahead with spread.

Digitized by Google

Figure 15–13 shows one quintuple-tube mount forward firing to starboard, and one aft, firing to port. The method involves clamping the tubes into certain positions, such as 55° for the forward mount and 305° for the after mount. Gyro settings are then made so that the mean torpedo track will be along own ship's course at the moment of firing. The ship is then swung until the tubes are correctly positioned for firing. Actual tube train angles and gyro settings used may be specified by fleet orders.

Curved fire ahead with spread was considered effective for long-range surface attacks. Since the resulting spread covers a large area, target ships are forced to maximum maneuvers to avoid being hit.

TUBE OFFSET

So far, we have been talking about torpedo fire from a single mount on a surface ship. In actual practice torpedoes are often fired in salvos from both forward and after tube mounts on surface ships as shown in figure 15–14. When such fire is conducted, tube offset *Otu* is used to get spread between the two tube mounts. The method of firing shown is straight fire with spread.

Find the basic torpedo course for the salvo as labeled in the illustration. This line represents the track which all the torpedoes would follow if neither gyro angle (to get spread between the torpedoes from a single mount) nor tube offset (to get spread between the torpedoes from both mounts) was used.

When tube offset is applied as shown in the illustration, the forward mount is trained a certain number of degrees forward of the basic torpedo course, and the after mount is trained the same number of degrees aft. The actual amount of tube offset is the angle between the tube mount axis and the basic tube train, and is measured either way from the basic tube train.

Notice the wide area covered when 10° tube offset is combined with spread gyro angle.

Digitized by Google

The two outside dotted lines show the tube axis for the two tube mounts. Since the basic torpedo course for each mount (*B'to* and *B''to*) is identical with the basic tube train (*B'tu* and *B''tu*) of that mount, both sets of letters are used in labeling the angles. This is true because in straight fire, *Bto* is always identical to *Btu*.

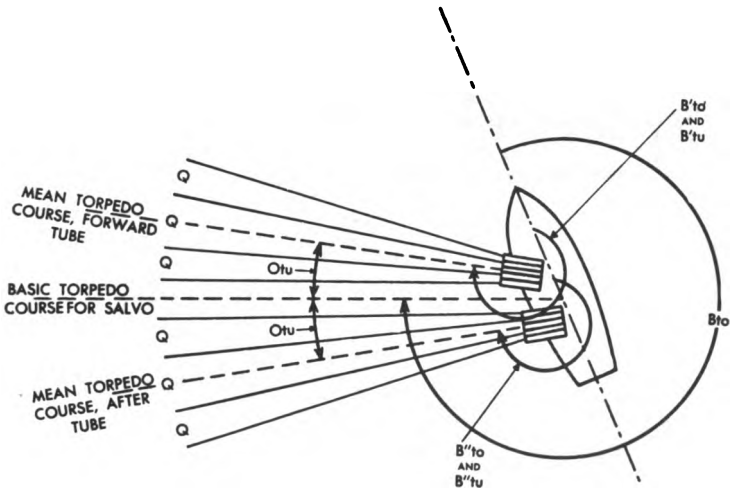


Figure 15–14.—Showing the use of tube offset.

The torpedo director must therefore be enlarged to include provision for (1) modifying basic tube train for tube offset, and (2) introducing and transmitting gyro angles. A description of a complete system follows.

TORPEDO DIRECTOR

Figure 15–15 is the complete schematic of the torpedo director. Provisions for modifying *Bto*, and introducing and transmitting basic gyro angle have been included. Tube offset is introduced through D–7 and D–8. Gyro angle is transmitted at two-speed and is shown on the inner ring dials of both the forward tube and after tube dial groups.

Digitized by Google

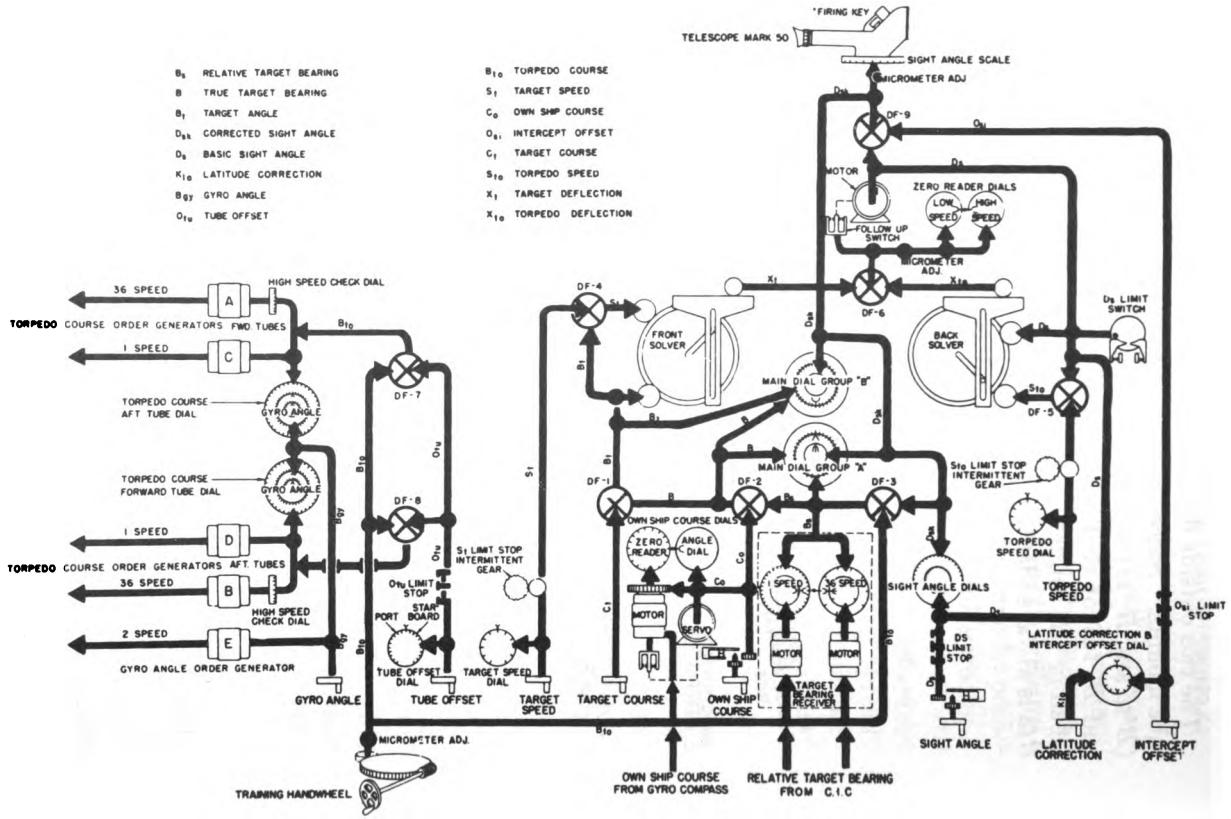


Figure 15–15.—Torpedo director schematic.

Digitized by Google

Notice the method used to convert inputs of target course into target angle. The standard conversion formula is $Bt = B + 180° - Ct$. Since B is obtained by adding $Co + Bs$ in D-2, the formula can be written $Bt = Co + Bs + 180° - Ct$. Bs in turn is derived from substracting $Bto - Dsk$ in D-3. The final formula as used by the director thus becomes $Bt = Co + Bto - Dsk - Ct + 180°$.

Target designation is received at the director by the relative target bearing receivers from CIC. If the problem is set up correctly, a continuous solution can be maintained by matching the generated and observed Bs dials. The telescope will continue to point at present target position which aids optical tracking when the target visibility is poor.

You should be able to figure the rest of the director out from the information associated with figure 15–10.

QUIZ

1. Which of the following is not used to furnish propelling energy in a modern torpedo?
   (*a*) Compressed air.
   (*b*) Gas and steam.
   (*c*) Chemicals.
   (*d*) Electricity.

2. The diameter of the torpedoes launched by PT boats and aircraft is usually
   (*a*) 13½ inches.
   (*b*) 15½ inches.
   (*c*) 21 inches.
   (*d*) 22½ inches.

3. Torpedo speeds range up to a maximum of about
   (*a*) 17 knots.
   (*b*) 27 knots.
   (*c*) 37 knots.
   (*d*) 47 knots.

Digitized by Google

4. The approximate maximum range of a torpedo in yards is
   (a) 15,000.
   (b) 16,000.
   (c) 17,000.
   (d) 18,000.

5. Which of the following units is NOT a part of the depth mechanism of a torpedo?
   (a) Pendulum.
   (b) Spring-loaded diaphragm.
   (c) Rudder.
   (d) Air flask.

6. The depth at which a torpedo will run can be determined by presetting
   (a) the up-down rudder.
   (b) the pilot valve position.
   (c) the pendulum position.
   (d) a spring tension.

7. When the torpedo decends to and reaches its predetermined depth, the pressure of the diaphragm is counter-balanced by the
   (a) pendulum .
   (b) gyro action.
   (c) depth motor.
   (d) water pressure.

8. Which of the following quantities is NOT affected by the apparent rotation of the gyro?
   (a) LOS.
   (b) *Dsk*.
   (c) *Bgy*.
   (d) Earth's LOF.

9. Which one of the following items does NOT affect the amount of creep?
   (a) Latitude.
   (b) Ocean currents.
   (c) Torpedo depth.
   (d) Time of torpedo run.

10. If the latitude correction weight is set to correspond to a latitude other than the firing latitude, creep will be proportional to the sine of the
   (a) highest of the two latitudes.
   (b) lowest of the two latitudes.
   (c) difference between the latitudes.
   (d) sum of the latitudes.

Digitized by Google

11. From the curves shown in figures 15–5 and 15–6, assuming a 10,000 r. p. m. gyro with its latitude correction set at 20° *S*, the amount of index correction per minute of torpedo run is
    (*a*) .027.
    (*b*) .042.
    (*c*) .085.
    (*d*) .143.
12. Using the data computed in question #11, the correction in degrees for a 20 minute run is
    (*a*) 0.54° left.
    (*b*) 0.84° left.
    (*c*) 1.7° left.
    (*d*) 2.9° left.
13. Which one of the following quantities is NOT considered in computing torpedo course?
    (*a*) Target course.
    (*b*) Target speed.
    (*c*) Torpedo speed.
    (*d*) Own ship's speed.
14. Creep, the curve of the torpedo's path away from the earth's line of fire, is zero at
    (*a*) latitude 60 degrees N.
    (*b*) latitude 60 degrees S.
    (*c*) latitude 00 degrees.
    (*d*) the North Pole.
15. The balance nut in the torpedo, which compensates for creep, is not always set for the firing latitude; this can be corrected by
    (*a*) setting in latitude correction *Kla* at the director.
    (*b*) setting in a gyro angle correction.
    (*c*) setting in a correction equal to the difference in degrees between the two latitudes.
    (*d*) setting in a correction equal to the first latitude.
16. The torpedo fire control problem forms a triangle, the sides of which are
    (*a*) own ship's run in yards, torpedo run in yards, and target run in yards.
    (*b*) target run in yards, torpedo run in yards, and the line of sight.
    (*c*) maximum torpedo range, ship's speed, and target course.
    (*d*) line of sight, line of fire, and target run in yards.
17. *Dsk*, corrected sight angle, is *Ds* plus
    (*a*) *Bgy*+*Kla*.
    (*b*) *Kla*+*Osi*.
    (*c*) *Kla*.
    (*d*) *Osi*.

Digitized by Google

18. Which of the following corrections is considered an arbitrary correction?
    (*a*) Latitude correction, *Kla*.
    (*b*) Intercept offset, *Osi*.
    (*c*) Sight deflection, *Ds*.
    (*d*) Tube offset *Osu*.
19. When the servo motor at the output of the *Xt* and *Xto* component solvers stops driving, which one of the following quantities has been solved?
    (*a*) *Ds*.
    (*b*) *Dsk*.
    (*c*) *Osi*.
    (*d*) *Klg*.

Digitized by Google

CHAPTER 16

UNDERWATER FIRE CONTROL

Antisubmarine warfare (ASW) is composed of two phases; (1) DEFENSIVE, which involves the use of nets and mine fields, and (2) OFFENSIVE, which is built around the sonar system. This chapter will deal only with offensive ASW.

Antisubmarine vessels, such as destroyer escorts, frigates, and subchasers, are designed chiefly for convoy duty. Convoys are usually routed around waters that are known to be submarine-infested to avoid enemy contact. However, if a vessel does make a sonar contact with an enemy sub, the ships protecting the convoy follow one important rule of antisubmarine warfare: ATTACK and REATTACK.

The most effective method of sinking subs is by a joint surface-air attack. The importance of aircraft and airships in antisubmarine warfare is considerable, for they can search a large area quickly, locate submarines and drive them under water with depth bombs and machine guns, and then guide surface craft to the scene. However, any aircraft is limited in its staying power and by the bomb load it can carry; it is best adapted to cooperating with surface craft which can pursue a submarine indefinitely.

If a submarine is contacted before it can submerge, a surface vessel will usually open fire with all guns and/or side-thrown charges and torpedoes, and may even maneuver to ram the sub.

Digitized by Google

The most effective weapons against submerged vessels are depth charges and ahead-thrown projectiles. Whenever an underwater attack is made on a submarine, the following is usually the routine.

1. Classify the sonar contact as a submarine.
2. Hold sound contact with the submarine.
3. Carry out an attack with either depth charges or ahead-thrown projectiles.
4. Regain contact.
5. Reattack.

DEPTH CHARGES

The familiar ash can is being replaced to a large extent by the teardrop or bomb-shaped depth charge. There are eight main types in use at present, and their characteristics and sinking times in seconds differ. These facts are tabulated in charts for use by the conning officer.

While some types of depth charges are exploded by either acoustic or magnetic action when they fall near a submarine, the one in most common use is the hydrostatically detonated type. Cast TNT surrounds the central tube of this charge. In one end of the tube is the booster mechanism; the other end contains the pistol or firing mechanism. On the outer face of the pistol is a graduated dial and pointer by which the charge can be set, at 50-foot intervals, to explode hydrostatically at depth down to 1,000 feet. The maximum depth possible depends upon which model pistol is used.

As the charge sinks, water is admitted to act on both the booster and pistol mechanisms. The booster mechanism is moved into firing position when the charge reaches a depth corresponding to a given water pressure. The firing pin is released when the charge sinks to a depth where the water pressure overcomes the spring pressure of the depth setting on the pistol mechanism. The firing pin fires the detonator into the booster charge, which in turn detonates the TNT.

Depth charges may be dropped from the racks at the stern, or fired from side throwers (K guns) which hurl them as far

Digitized by Google

as 125 yards on the beam. Ships lacking side throwers are limited to dropping charges only along a straight line. But if K guns are added, any one of several standard patterns may be fired. The type of pattern depends upon the situation and the number of throwers.

While the attack is always calculated with reference to one charge—the center one of the pattern—the extensive possibility of an error makes the use of additional charges necessary. Therefore they are ordinarily dropped in patterns. The charges are set to explode at various depths in the water beneath the surface covered by the pattern.

Explosives fired under water can do greater damage than a corresponding amount of explosive set off in the air. Nevertheless, modern submarines are so strong that a charge must explode within 6 yards of the pressure hull to have lethal effect.

Explosions immediately beyond the lethal range may indirectly cause the destruction of the submarine through leaks in the hull, jamming of the hydroplanes, or other forms of damage. Then, too, it is always possible that a frightened crew member will turn the wrong valve and either sink the sub or bring it to the surface. It is difficult, however, to tell whether you have destroyed a submarine unless unmistakable evidence in the form of essential equipment from within the hull comes to the surface.

Depth Charge Patterns

The depth charge pattern is a plan for dropping depth charges. There are two major patterns, known as DISTRACTING and DESTRUCTIVE.

The distracting pattern is laid to harass the sub and prevent accurate torpedo fire. It consists of one or more charges fired immediately, with shallow settings, in an attempt to drive the submarine down and prevent it from firing torpedoes. The distracting charge may not damage the submarine. It is fired merely as a defensive move to protect the ships in the convoy.

Digitized by Google

The purpose of a destructive attack, however, is just what the name implies. The pattern is dropped in such a way that the center charge of the pattern will explode against the submarine. The destructive pattern is the standard full pattern of charges that can be fired by an attacking vessel. It is the whole works.

The chief difficulty with any attack is the time required for the charges to sink. The obsolescent 750-pound ash can, for example, required about 40 seconds to reach a depth of 250 feet. During this time the submarine could maneuver without interference. In 40 seconds an 8-knot submarine can travel 180 yards, make a 60° turn, or even change its depth by 60 feet.

We have a repetition of the situation encountered in gunfire. Unless the submarine is stationary, you can no more

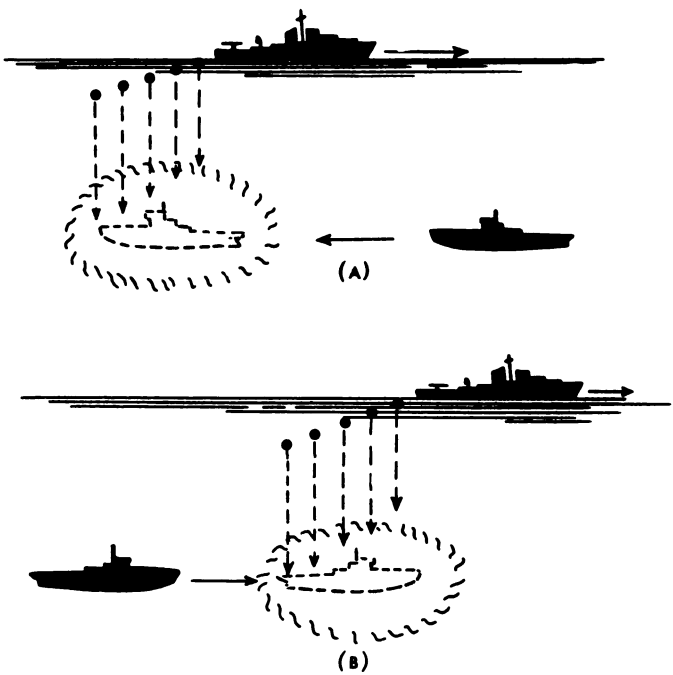


Figure 16–1.—Drop D/C's ahead of the target.

Digitized by Google

drop the charges directly over it than you can fire a gun directly at a moving target and expect to score a hit.

If the submarine is moving straight along the attacking ship's path, it is a simple matter to compensate for the sinking time of the charges. If you are approaching the submarine head on, drop the charges before passing over the submarine. When approaching from astern, drop the charges after passing over the submarine. (Fig. 16–1.)

In both the bow-on and stern-on attacks, the submarine commander has a good chance to evade the attacking ship—and he will if possible. Sonarmen aboard the submarine can hear the attacking ship, and the submarine will never move along the ship's track.

If a pattern were laid as shown in figure 16–2A the submarine could evade by turning in either direction. The A/S vessel, therefore, must counter the submarine's evasive tactics by a maneuver similar to the one shown in figure 16–2B. Even though the submarine tries to turn it may come in contact with one of the charges of the pattern. This is accomplished by the following procedure.

When sonar contact is made, the A/S ship is brought to a course which will take it across the bow of the submarine, and sufficiently far ahead to allow for the sinking time of the charges. Thus the depth charges will explode at the same time the sub reaches them.

The conning officer must know the range, and the approximate bearing, course, speed, and the depth of the sub in order to steer the proper course. Even with all this information, however, the attack course selected is subject to change at any moment because of the sub's maneuvers. Unfortunately these maneuvers may go undetected. At very short ranges, 150 yards or less, the return echo of the sonar equipment cannot be distinguished from the outgoing signal. Also, contact may be lost at longer ranges: for example it is possible to lose contact at 700 yards if the sub is deep enough. Thus the sub's position will often not be known exactly in the last stages of the attack.

Digitized by Google

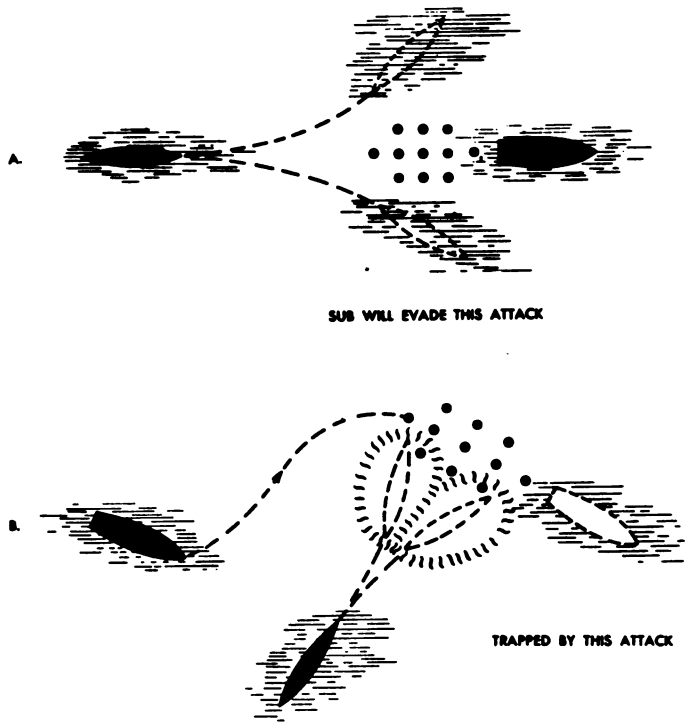


Figure 16–2.—(A) Sub will evade this attack. (B) Trapped by this attack.

To reduce both the length of this "silent period" and the chances of evasion by the sub, the surface vessel should attack at the highest speed possible. The conning officer must also make certain that his ship will clear the explosions of the stern-dropped charges. The maximum attack speed, however, is limited. At high speeds the water noises caused by the sonar projector traveling through the water may obscure the sound echoes from the sub.

This silent period can be overcome through the use of a coordinated attack by two ships.

The echoing ship stays about 1,500 yards from the submarine and maintains constant sonar contact. It then furnishes the attacking ship with the proper course, speed,

Digitized by Google

and firing time. The attacking ship does not echo range, but may listen. Thus the silent period is eliminated, since the echoing ship never loses sonar contact with the sub. Furthermore, the submarine commander never knows which ship will attack.

AHEAD-THROWN WEAPONS

There are two types of weapons for ahead-thrown attacks: the projector and the rocket launcher (fig. 16–3). Both types are located on the forecastle, and fire their charges ahead in the direction of ship movement. Each charge contains approximately 30 pounds of cast TNT and will explode if it strikes an object in the water. They are also countermined—if one explodes by impact, the remainder are detonated simultaneously by the resulting pressure waves.

The projector can be trained from dead ahead to 20° on either side of the bow. It is designed to fire a group of 24 charges, in pairs, at intervals between pairs of about 0.1 second. The twelve pairs are fired in a total time of from 1 to 1.5 seconds, and form a roughly elliptical pattern (fig. 16–4) as they fall in the water.

During an attack, the Sonarman holds contact with the sub and furnishes the conning officer with continuous ranges and bearings. The conning officer then keeps the ship headed at the target and comes in for the attack at a speed not greater than 10 knots. Because the charges have a fixed range, the pattern must be fired when the ship reaches the correct firing range. The correct firing range, of course, depends upon many factors which are calculated by the range recorder.

Improved projectors are now being installed on antisubmarine vessels. These projectors can be trained on either side of the ship's bow, and are stabilized in level and cross level by a stable element.

The effectiveness of the projectors is greatly increased by stabilizing the projector against the roll and pitch of the ship. Any last-minute evasive maneuvers of the submarine

Digitized by Google

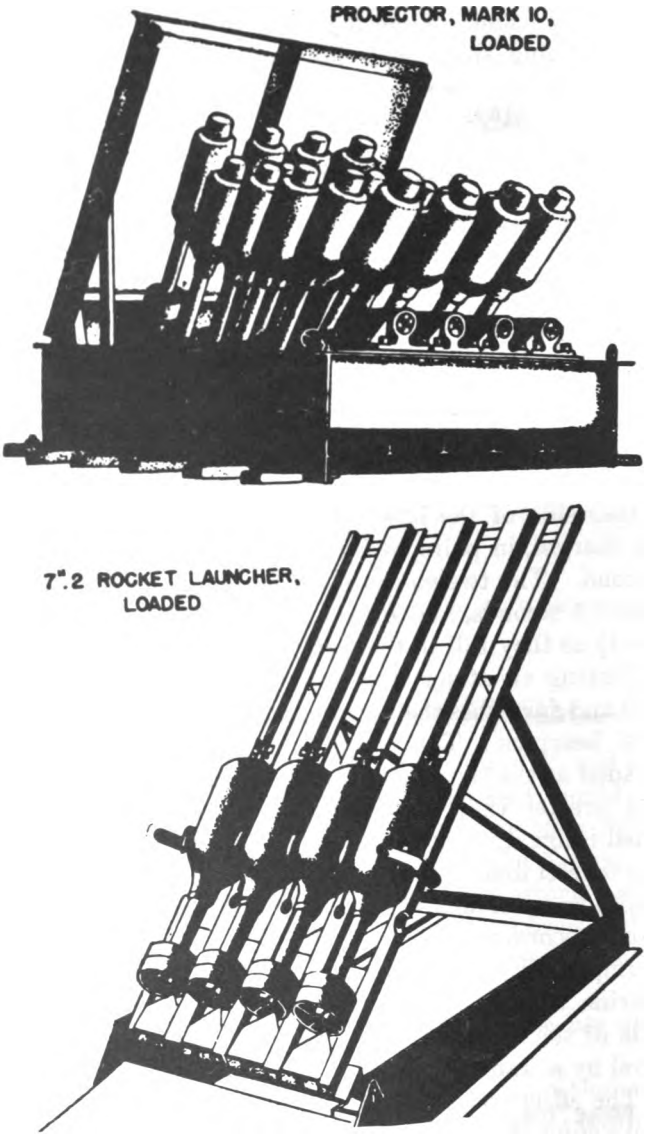


Figure 16–3.—The nonstabilized projector and the rocket launcher.

Digitized by Google

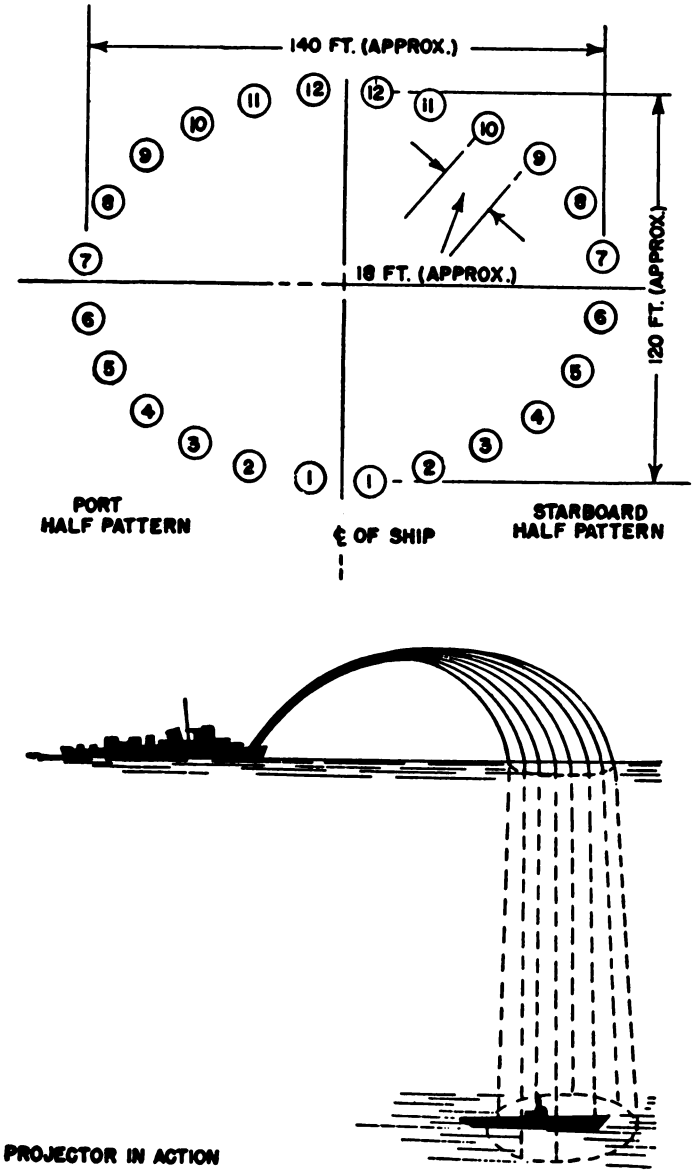
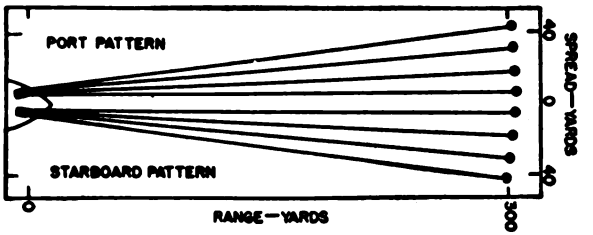


Figure 16–4.—The projector in action.

Digitized by Google

can be compensated for by merely modifying the angle of projector train. Moreover, since the projector is stabilized, it is not necessary to delay firing the ahead-thrown weapons until some predetermined point in the ship's roll is reached.

The lower rocket launcher of figure 16–3 is composed of a set of steel ways for supporting and firing 7.2-inch rockets. Usually two launchers are mounted facing forward—one to port and one to starboard on the foredeck (fig. 16–5). Each launcher, depending upon the type, fires either four or eight rockets in a salvo.



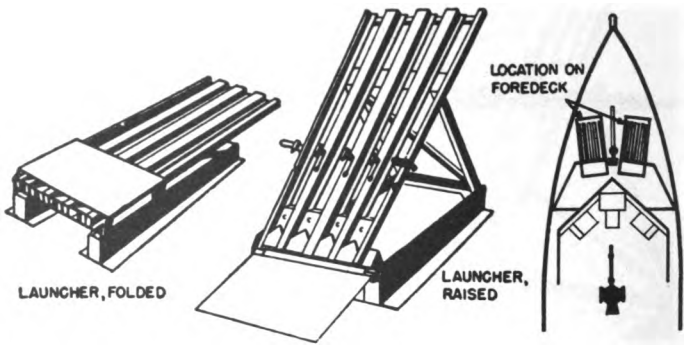


Figure 16–5.—The rocket launcher.

The body of the rocket is 7.2 inches in diameter and 35 inches long. It is filled with 30 pounds of explosive which is detonated either by impact or countermining.

A small ship, using two of these four unit launchers, can fire a salvo of eight rockets. The rockets are propelled

Digitized by Google

through the air by reaction from the burning powder in the motor tail, and strike the water 300 yards forward of the firing point. They fall in a straight line 83 yards long, and at right angles to a line through the center of the firing ship (fig. 16–5).

The procedure for the attack is similar to that employed with the projector. The ship must be headed correctly at the target and the rockets fired at an exact range.

The later type rocket launchers, now in service aboard antisubmarine vessels, are equipped with train power drives and are stabilized in level and cross level as already mentioned.

TYPES OF ATTACK

There are two types of attack depending upon the tactical situation. They can be classified as urgent and deliberate.

An urgent attack is carried out when the convoy is in immediate danger. The A/S ship, if possible, employs a full destructive pattern. But if there is a possibility of the submarine firing a torpedo before you can attack with a full destructive charge, the distracting pattern is used first.

A deliberate attack is made whenever time permits, or when the convoy is in no immediate danger. Ahead-thrown weapons are used when available. If the sub is deeper than 400 feet or lying on the bottom, a full destructive pattern is fired.

THE ATTACK PROBLEM

The underwater attack problem is similar in some respects to the surface fire control problem. For example, own ship and target motion are resolved into horizontal components in and across the vertical plane containing the line of sound. But instead of calculating gun orders, we are interested in the course along which own ship must be steered, *cCo*, and the time to fire, *Tud*. By definition, *Tud* is the time remaining until the charge is to be fired.

Certain other values, however, must first be obtained in order to solve for *cCo* and *Tud*. They are:

Digitized by Google

1. Yt and Xt Horizontal components of target velocity, in and perpendicular to the line of sound.
2. $\Delta cBrq$ Increments of generated relative sonar bearing.
3. $\Delta cRhq$ Increments of generated horizontal sonar range.
4. $cRhq$ Generated horizontal sonar range.

Let us see how these values are obtained.

Figure 16–8, the geometry of the problem, has been superimposed on the perspective view of figure 16–7. These illustrations show the target and own ship on a straight course. But as stated previously, the problem usually develops with the target and own ship on curved rather than straight courses. In computing the problem, however, it is assumed that, at any instant, both own ship and target are on straight line courses tangent to their respective curves (fig. 16–6).

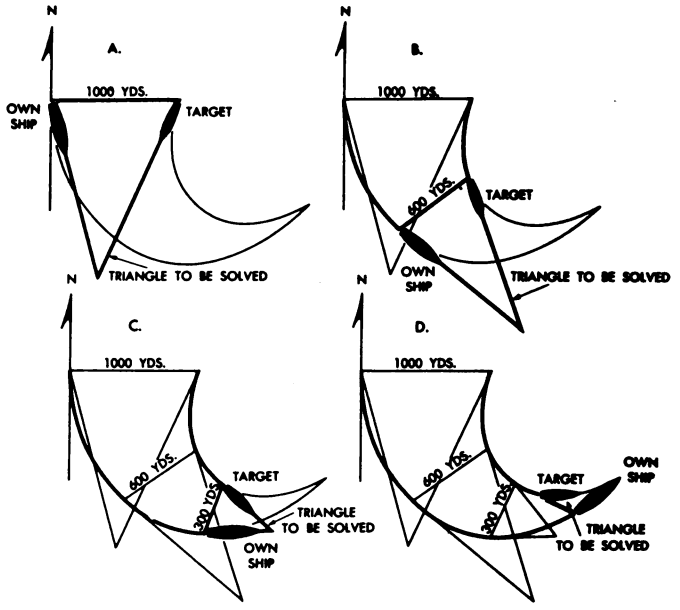


Figure 16–6.—Progression of attack problem (curved course).

Digitized by Google

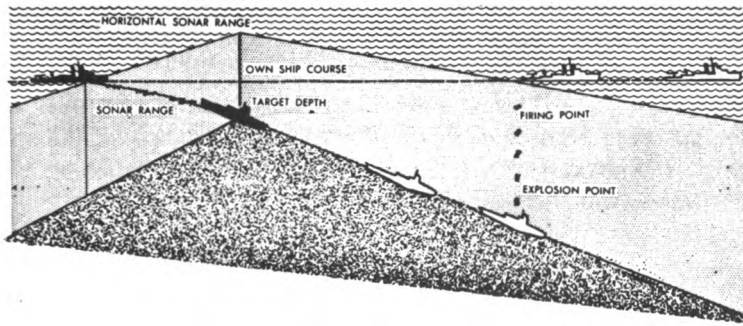


Figure 16–7.—Attack problem in perspective.

Therefore we can progressively solve triangles similar to those shown in figure 16–8. This diagram contains all the factors necessary for the solution of the attack problem.

NOTE: The symbols employed here are quite similar to those used in surface fire control. A glossary defining each is located at the end of this chapter.

In figure 16–8, own ship (the attacking vessel) is moving along the dotted line forming one side of the *jCo* angle, while the target is moving along the projected line designated *S*. The range between the two ships at this instant is *cRhq*. But own ship should be on the course indicated by the line *So* in order to intercept the target as soon as possible, and yet not exceed the maximum speed at which the echo ranging equipment is efficient. Therefore own ship course must be altered by the correction angle *jCo*.

After its course has been corrected, own ship moves along line *So* a distance *SoTud* (own ship speed multiplied by the time to fire) to position 2. The word to fire is given at this point. Because of dead time *Tg*, between the word to fire and the release of the charges, however, own ship proceeds a distance *SoTg* to position 3 before the charges leave the ship.

While the charges are sinking to their computed depth, own ship advances from position 3 to 4, a distance *SoTd* (own ship speed multiplied by the sinking time). Simultaneously, the submarine will have proceeded along its

Digitized by Google

course—provided the values have been computed correctly—to a point directly beneath position 3, and at a depth corresponding to the depth of the explosion.

The horizontal distance between the sonar transducer and the point where the charges hit the water, measured at the instant of explosion, is designated *Rhd*. The importance of this value will be discussed later.

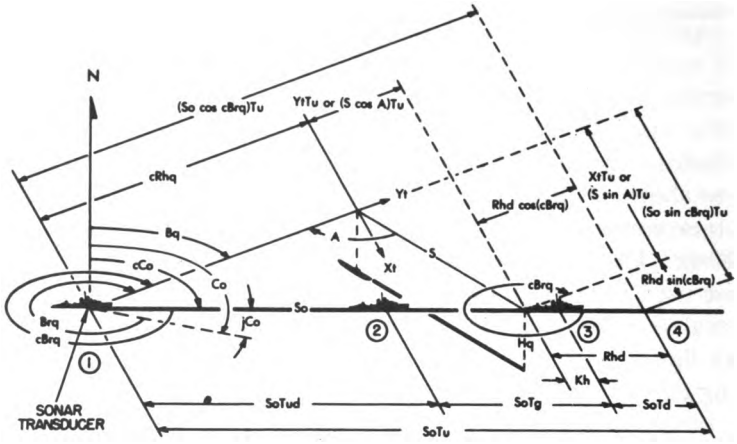


Figure 16–8.—Stern-dropped attack problem.

Since all computations are based on the position of the sonar transducer at a given time, the value *Rhd* must include the horizontal base line *Kh*, measured from the sonar transducer to the stern. Thus $Rhd = Kh + SoTd$.

In computing target course and speed, the target's total motion is figured with reference to the horizontal projection of the line of sound and equals the vector sum of the target's motion in and across this projection of the line of sound. The target's vectors are indicated in figure 16–8 in a vertical plane through the projected line of sound by Yt ($S \cos A$) and perpendicular to this vertical plane by Xt ($S \sin A$).

The total target motion parallel to the vertical plane through the reference line of sound is equal to the product of

Digitized by Google

target speed component in plane of sound and time traveled by the target, or time to explosion *Tu*. As shown in figure 16–8, the value of this product is designated *YtTu*.

The total target motion perpendicular to the vertical plane through the reference line of sound is equal to the product of target speed component across plane of sound and time traveled by the target, or time to explosion *Tu*. As shown in figure 16–8 the value of this product is designated *XtTu*.

Own ship's motion equals the vector sum of own ship's motion in and across the reference line of sound. Own ship's total motion in the reference line of sound is *YoTu* which is equal to (*So* cos *cBrq*) × *Tu*, and own ship's total motion across the line of sound is *XoTu* which is equal to (*So* sin *cBrq*) × *Tu*.

The distance *Rhd*, own-ship travel between the actual time of firing (position 3) and time of explosion *Tu* (plus distance *Kh*), is likewise resolved into components in and across the reference line of sound. These values, as shown in figure 16–8, are *Rhd* cos *cBrq* and *Rhd* sin *cBrq* respectively.

The Solution for cCo

In the mathematical solution for *cCo* and *Tud*, certain geometric and trigonometric relationships may be derived from figure 16–8. These are:

1. *So* cos *cBrq Tu*+*YtTu*=*cRhq*+*Rhd* cos *cBrq*.
2. *So* sin *cBrq Tu*+*XtTu*=*Rhd* sin *cBrq*.

The sign of *YtTu* and *XtTu* depends upon the quadrant in which the target angle lies. (In the figure the target angle lies between 90° and 180° and its cosine is minus.) The above equations may be written:

3. *Tu* (*So* cos *cBrq*+*Yt*) = *cRhq*+*Rhd* cos *cBrq*.
4. *Tu* (*So* sin *cBrq*+*Xt*) = *Rhd* sin *cBrq*.

Equations 3 and 4 can be cross-multiplied; and *Tu* is eliminated from the equation by cancellation.

5. (*So* cos *cBrq*+*Yt*) (*Rhd* sin *cBrq*) =
   (*So* sin *cBrq*+*Xt*) (*cRhq*+*Rhq* cos *cBrq*).

Digitized by Google

The above equation can be solved for *cBrq*, since *So* is known and *Xt*, *Yt*, *cRhq*, and *Rhd* can be obtained as will be seen later.

Computed value *cBrq* is then subtracted from measured value *Brq* to determine the difference *jBrq*, which is numerically equal to *jCo*, the correction to own ship course:

6. $Brq - cBrq = jBrq.$
7. $Brq - cBrq = jCo.$

The quantity *jCo* is transmitted as a correction to own ship course, and represents the difference between own ship course *Co* and own ship course order *cCo*:

8. jCo (as a correction) $= cCo - Co.$

When own ship is on the ordered course *cCo*, the correction to own ship course *jCo* equals zero, and own ship is on the correct course for the solution of the attack problem. Thus one important factor in the problem has been solved.

Solution for Time to Fire, *Tud*

The value of time to the explosion *Tu* must be known to compute time to fire *Tud* (the other important factor which must be solved). *Tu* is solved for in the following manner:

Equation 5 was solved to obtain *cBrq*. Then if this computed value of *cBrq* is substituted in equations 3 and 4, we have two equations (both of which affect the solution) with one unknown, which is *Tu*. Equations 3 and 4 can be added, giving:

9. $Tu\ (So \cos cBrq + Yt) + Tu\ (So \sin cBrq + Xt) = cRhq + Rhd \cos cBrq + Rhd \sin cBrq.$

Tu can be factored out of the left-hand member of the equation and an expression for *Tu* obtained:

10. $Tu\ (So \cos cBrq + Yt + So \sin cBrq + Xt) = cRhq + Rhd \cos cBrq + Rhd \sin cBrq$, or

$$Tu = \frac{cRhq + Rhd \cos cBrq + Rhd \sin cBrq}{So \cos cBrq + Yt + So \sin cBrq + Xt}.$$

Digitized by Google

Once Tu (time until the charge explodes) is known, we can solve for Tud, the time remaining until the order to fire is given. Referring to figure 16–8 again, it may be seen that:

11. $SoTu = SoTud + SoTg + SoTd$.

Dividing both sides of the equation by So and rearranging terms, equation 11 becomes:

12. $Tud = Tu - (Tg + Td)$, which gives the time to fire for the stern-dropped attack.

Solution for the Ahead-Thrown Attack

Figure 16–9 shows in perspective the geometry of the ahead-thrown attack problem. The factors involved in this problem are the same as for the stern-dropped depth-charge attack, with one main difference, which is the solution for

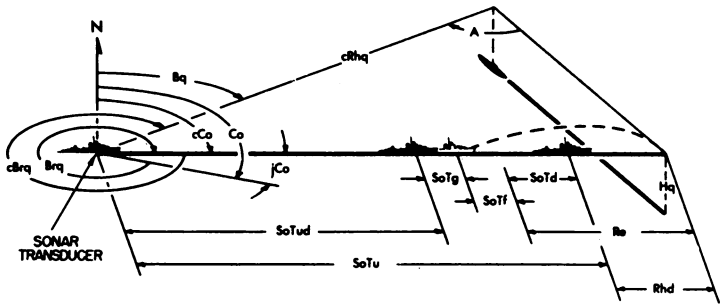


Figure 16–9.—Ahead-thrown attack problem.

Tud. In this solution Tf, which is the time the missiles are in the air, must be considered. Therefore, the following formula may be set up:

13. $SoTud = SoTu - (SoTg + SoTf + SoTd)$.

Dividing by So, the time to fire for the ahead-thrown attack is given:

14. $Tud = Tu - (Tg + Tf + Td)$.

Factors Common to Both Forms of Attack

Equation 14 may be taken as the general equation for Tud (time remaining until the drop) regardless of whether a

Digitized by Google

stern-dropped or an ahead-thrown weapon attack is employed, noting that if stern-dropped charges are used the value of Tf is zero.

Dead time $T'g$ is a constant value for any particular crew, ship, and method of attack.

The time of aerial flight for ahead-thrown missiles, Tf, is also a constant. Sinking time Td is a known value, determined by the sinking rate of the charge Sd, and the target depth Hq:

15. Td in seconds $= \dfrac{Hq \text{ in feet}}{Sd \text{ in feet per second}}$.

Solution of Rhd: Own ship must be a safe distance from the explosion if damage to own ship is to be avoided. This distance Rhd (depth-charge explosion range) is measured from the sonar transducer, in a horizontal plane, to a point directly above the explosion.

In a stern-dropped attack (see fig. 16–8), it is imperative that own ship move this minimum horizontal distance between the time the charges are dropped and the time of the explosion. Therefore, Rhd is computed by using the values of own ship speed, sinking time, and Kh, the horizontal base

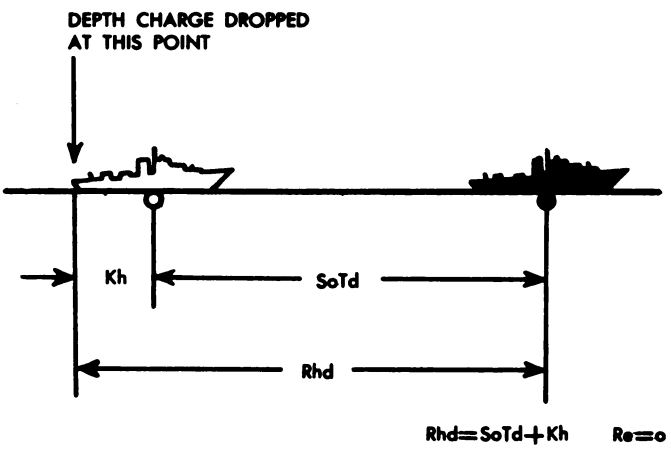


Figure 16–10.—*Rhd* solution for stern-dropped attacks.

Digitized by Google

line. Then this value of *Rhd* can be compared at a glance with the depth-charge explosion range of any given type of depth charge. Calculated *Rhd* is:

16. $Rhd = SoTd + Kh$ (for stern-dropped attacks, fig. 16–10).

Referring now to figure 16–11, *Rhd* can be computed for ahead-thrown attacks in a similar manner.

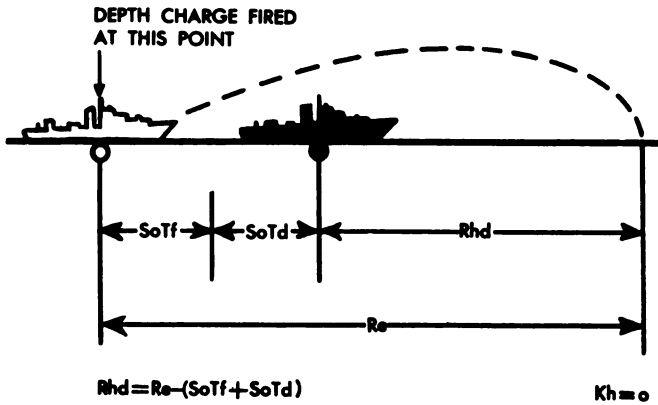


Figure 16–11.—*Rhd* solution diagram for ahead-thrown attack.

17. $Rhd = Re - (SoTf + SoTd)$

where *Re* is the effective horizontal range of the ahead-thrown weapons, and *Kh* is zero since the projector is almost directly above the sonar transducer.

It was stated previously that there is a maximum safe speed during an attack with ahead-thrown weapons. If equation 17 is rearranged, and the minimum safe value of *Rhd* substituted, solving for *So* the equation then reads:

18. Maximum Safe Speed $= \frac{Re - Rhd}{(Tf + Td)}$.

Equation 16 for stern-dropped attacks, and equation 17 for ahead-thrown attacks can be combined and written in the general form:

19. $Rhd = Re - (SoTd + SoTf + Kh)$.

Digitized by Google

If stern-dropped attacks are used, *Re* is zero and *Rhd* has a negative value, which means that own ship is ahead of the explosion. In ahead-thrown attacks *Re* has a value, while *Kh* is zero. Furthermore, in this case *SoTd* is smaller than *Re*, and *Rhd* will have a positive value, which means that the explosion will occur ahead of own ship.

Generated Rates

Components of target motion in and across the line of sound, *Yt* and *Xt*, are necessary for the solution of the problem. Instead of introducing target angle and target speed initially to obtain these components, as is done in the gun fire control systems, the director mechanism generates *Yt* and *Xt* from the measured sonar range and bearing. This is logical since there is no ready way to measure course and speed of a submerged submarine.

It is possible to plot sonar ranges and bearings to obtain *A* and *S*, but the director eliminates this step and computes directly the *Xt* and *Yt* components through a series of regenerative steps to be described shortly. Then the sonar operators exercise rate control by comparing the generated and observed values of sonar range and bearing, and they change the generated (or computed) values to agree with the observed values. The changes thus introduced are transmitted to the director, which then works out corrections to the *Xt* and *Yt* components. When the generated and measured values agree, the solution is correct.

To COMPUTE these corrections, we start with the *X* and *Y* components, which are added to obtain rates in and across the line of sound.

Thus *Yo* plus *Yt* equals *dRhq*, or

20. $dRhq = So \cos cBrq + Yt$ (see fig. 16–12),

which is the formula for horizontal sonar range rate in yards per hour. This rate is changed to yards per second by multiplying by 0.563. When integrated against time, *dRhq* becomes increments of generated horizontal sonar range rate, $\Delta cRhq$

Digitized by Google

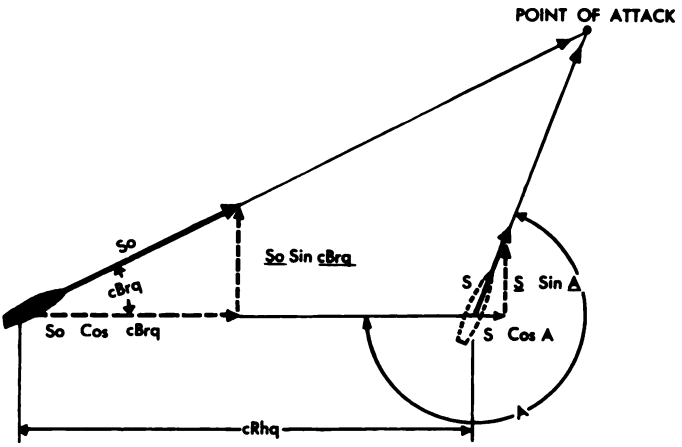


Figure 16–12.—Own ship and target components.

(fig. 16–13). $\Delta cRhq$ is instrumental in the manufacture of the correction to horizontal range component of target velocity jYt. In turn, the attack director integrates jYt against time and adds the integrator output to the manual input, Ytj, to produce increments of the changes in the target rang

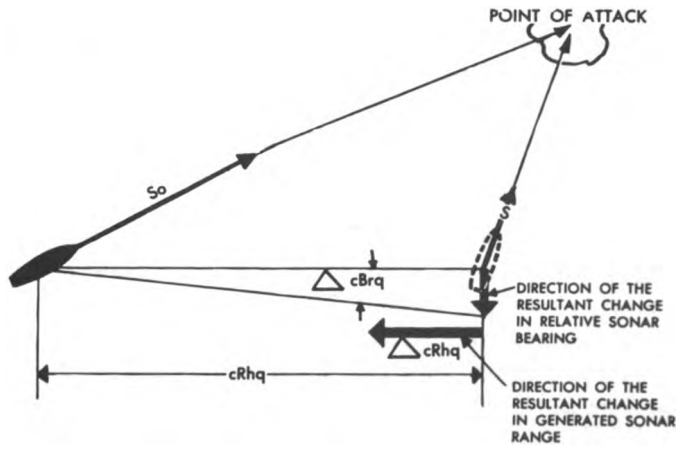


Figure 16–13.—Increments of the generated rates.

Digitized by Google

component ΔYt. This quantity is then added to the original value of Yt to produce a new corrected Yt, which, of course, feeds back to correct $dRhq$. The section of the attack director that accomplishes this is called the Yt generation mechanism.

Similarly, the linear sonar deflection rate $RdBsq$ is equal to the sum of Xo and Xt, or

21. $RdBsq = So \sin cBrq + Xt$ (see fig. 16–12).

This rate is now integrated against time, and divided by $cRhq$ to produce increments of generated relative sonar bearing $\Delta cBrq$ (fig. 16–13). $\Delta cBrq$ is used to produce jXt, the correction to horizontal deflection component of target velocity. The quantity jXt is processed in exactly the same way as the range component to give ΔXt, the increments to the changes of the target deflection component. The resulting corrected Xt feeds back to correct $RdBsq$.

Of course, when the generated and observed quantities match, the automatic corrections jYt and jXt are zero.

The increments $\Delta cBrq$ and ΔcRq are sent to the sonar equipment to aid tracking in bearing and range. Notice that ΔcRq is used instead of $\Delta cRhq$. By definition, Rq is the range to the target along the line of sound. Thus, when ΔcRq is added to the initial range setting Rqj at the sonar equipment, we have generated sonar range cRq which is compared with the sonar range Rq at the sonar equipment.

It should be apparent from the preceding discussion that the sonar tracking aid section functions in a way very similar to that of the surface rangekeeper covered in a previous chapter.

ELEMENTS OF THE SYSTEM

The UWFC system on board the general-purpose destroyer normally consists of the following units:

1. The SONAR EQUIPMENT. Such units as the sonar transducer and transmitter comprise this equipment.
2. The ATTACK DIRECTOR. This is the computing element of the system used to solve the problem just described. It will be further discussed in this section.

Digitized by Google

3. The ATTACK PLOTTER. This unit displays electronically on a large scope a picture of the movement of own ship and target. It may be used as an auxiliary in determining *cCo* and *Tud* graphically, in case of failure of the attack director. In addition, an auxiliary instrument, called the remote-spot transmitter, makes it possible to display on this scope the location of another vessel, thus making the attack plotter useful in multiship action.
4. The SONAR RANGE RECORDER. This device automatically records the sonar range received from the sonar equipment. The range obtained by each "ping" is indicated as the horizontal coordinate on a sheet of paper which is moved vertically at a constant rate proportional to time. Therefore it visually indicates ranges to the target at the time they were taken. The slope of the imaginary line connecting the range marks is a measure of the range rate, which method is similar to the one used in the graphic plotter in the surface fire control system. The range recorder may be used as an auxiliary means of determining *Tud* in case of failure of both the attack director and the attack plotter. However, its primary function in the normal operation of the system is to provide a means for determining (1) the difference between observed and generated range and (2) the actual range rate.
5. The WEAPONS. These consist of depth charges and ahead-thrown missiles previously discussed. Specialized antisubmarine ships are receiving more advanced weapons and control systems. However, their security classification does not permit inclusion in this chapter.

The Attack Director

The function of the attack director (see fig. 16–14) is to solve the fire control problem discussed earlier, that is, to obtain *cCo* and *Tud*. In order to do this the attack director must receive certain inputs. These are:

Digitized by Google

Figure 16–14.—Face of an attack director.

Digitized by Google

AUTOMATIC INPUTS. The automatic inputs are:

1. Own-ship course *Co*, from the ship's gyro compass transmitter.
2. Own-ship speed *So*, from the ship's pitometer log system.
3. Relative sonar bearing *Brq*, from the sonar equipment.
4. Sonar range *Rq*, from the sonar range recorder.
5. Correction to sonar range *Rqj*, from the sonar range recorder.

MANUAL INPUTS. The manual inputs are as follows:

1. Horizontal baseline *Kh*, or effective range *Re* (depending on method of attack).
2. Time of flight *Tf*, plus dead time *Tg*.
3. Target depth *Hq*. } By setting these values *Td* is intro-
4. Sinking rate *Sd*. } duced.
5. Manual correction to *Xt* (*Xtj*).
6. Manual correction to *Yt* (*Ytj*).

Using these inputs the attack director solves the problem, using mechanical methods (in this case a linkage type of computing mechanism) to solve the equations previously discussed. The mechanics of this solution are similar to those employed in computers used in the surface system, so will not be discussed further here.

AUTOMATIC OUTPUTS. Figure 16–14 shows the face of the attack director, showing the dials for indicating the manual and automatic inputs and outputs, and knobs for manual inputs. The automatic outputs are:

1. Own-ship course correction *jCo*.
2. Time to fire *Tud*.
3. Generated sonar range *cRq*. (*cRq* includes ΔcRq, the generated increments of sonar range, and *Rqj*, sonar range correction.)
4. Increments of generated relative sonar bearing $\Delta cBrq$.
5. Target speed *S*.
6. Target angle *A*.
7. Range rate *dRhq*.

Seven dials appear on the face of the attack director,

Digitized by Google

and readings on these dials are used in setting up and analyzing the problem.

The following values may be read on these dials:

1. HORIZONTAL RANGE DIAL. Generated horizontal sonar range *cRhq*.
2. RANGE-RATE DIAL. Range rate *dRhq*.
3. TIME-TO-FIRE DIAL. Time to fire *Tud*.
4. OWN-SHIP SPEED DIAL (not included on some models). Own ship speed *So*.
5. COURSE-ORDER DIAL GROUP. Own-ship course *Co*, true sonar bearing *Bq*, own-ship course order *cCo*.
6. TARGET COURSE and SPEED DIAL. Target course *Ct*, target speed *S*.
7. TARGET ACCELERATION DIAL. Target acceleration.

Operation of the Attack Director

In setting up the problem on the attack director the automatic inputs are continuously received whenever the director and associated equipment are in operation. The setting of the manual inputs will depend on the type of attack, the weapons used, and the depth of the submarine. In a stern-dropped depth charge attack *Kh* is set on the *Kh/Re* dial, the sinking speed for the type of depth charge being used is set on the sinking-speed dial, and the dead time is set on the *Tf+Tg* dial. In ahead-thrown attack *Re* is set on the *Kh/Re* dial, *Tf+Tg* on the *Tf+Tg* dial, and the sinking speed of the projectile on the sinking speed dial. Target depth cannot be accurately set until sonar contact is made with the submarine, at which time the depth-determining sonar will establish that value. If depth-determining equipment is not installed, depth is estimated from the most accurate data available.

The Relative-Motion Picture

The visual presentation of the relative-motion picture and indications of a stable solution of this problem are provided by the course-order dial, target course and speed dial, and

Digitized by Google

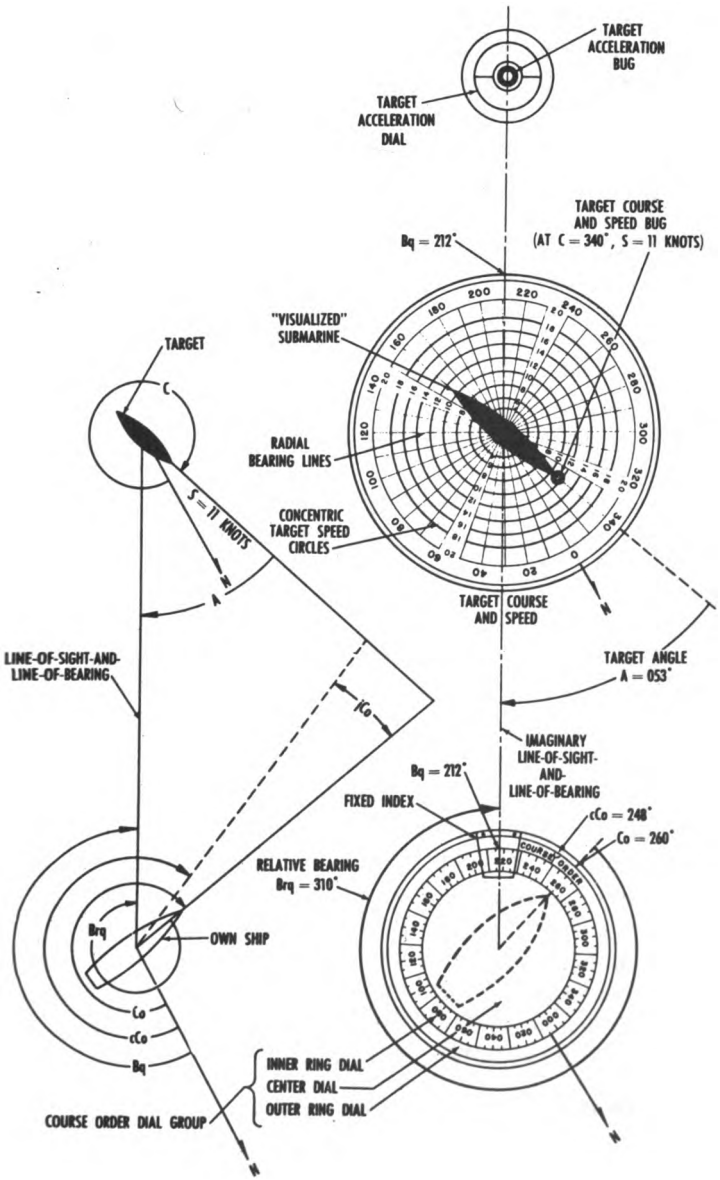


Figure 16–15.—Own-ship and target group.

Digitized by Google

target acceleration dial. (See fig. 16–15.) As shown in the figure the values of own ship's course (*Co*), own ship's course order (*cCo*), and true bearing (*Bq*) may be read directly on the course-order dial. Relative bearing (*Brq*) may be estimated indirectly by the equation $Brq = Bq - Co$.

The target course and speed dial has a circular bug (or indicator mark) which is positioned by the attack director. The position of this bug on the dial indicates target course and speed. The center of this dial represents the conning tower of the submarine, while the bug represents its bow.

The target acceleration dial has a bug whose movement from the center of the dial indicates that target course and speed are changing and that the problem is therefore not solved. When correct solution is being generated this bug should be centered.

By proper use of the dials described above, the operator can visualize the attack as it progresses and thus be prepared to take proper corrective measures. Own ship is shown, and the target can be imagined on its dial. The imaginary line joining the centers of the course-order dial and the target course and speed dial represents the line of sound. (See fig. 16–15.)

Further, any movement of the target acceleration bug indicates that a similar and parallel movement of the target course and speed bug is about to take place. A movement of the acceleration bug indicates that observed and generated values of *Brq* and *Rq* are not the same. When observed values of relative sonar bearing *Brq* or sonar range *Rq* differ from the values generated by the attack director, corrections are required from bearing and range operators. The attack director will accept the correction and generate a corrected solution. The target acceleration bug then returns to the center of its dial when this solution is stable.

Use of *Xt* and *Yt* Correction Knobs

The stabilization of the solution as described above may take a considerable time if the change in target course and

Digitized by Google

speed is large. The solution can be speeded up by judicious use of the *Xt* and *Yt* correction knobs by the director operator.

As mentioned above, the target acceleration bug indicates the directions in which movement of the target course and speed bug can be expected. The distance the course and speed bug will move will, however, be only about half that of the target acceleration bug. Therefore, by manually manipulating the *Xt* and *Yt* knobs the target course and speed bug can be made to move quickly to its corrected position as indicated by the target acceleration dial.

This helps adjust the solution very quickly. However, overcompensation may actually delay solution of the problem, and inexperienced operators should not attempt to use the *Xt* and *Yt* correction knobs, but rather should wait for the director to stabilize the solution by itself.

OVER-ALL OPERATION

The ATTACK DIRECTOR solves the relative-motion problem and computes increments of bearing $\Delta cBrq$ and range ΔcRq, which provide means for comparing generated values with measured values and thus introduce needed corrections *jBq* and *Rqj* into the solution of the problem. When computed values of range and bearing are not in agreement with measured values, the target acceleration bug moves off center; corrections to the solution will be automatic, but may be speeded by hand inputs *Xtj* and *Ytj*. The director computes final values *cCo* and *Tud*.

No provision is made for hand inputs of own ship course, speed, and range to the attack director. In the event of failure of the attack director, the ATTACK PLOTTER may be used to solve the problem. The attack-plotter operator tracks the target during attacks and is ready to assume control at once. Course-to-steer order can be switched to the attack plotter by throwing a switch in UB (underwater battery) plot. Time to fire can be taken from the attack plotter or sonar range recorder (fig. 16–16). In ahead-thrown attacks the firing

Digitized by Google

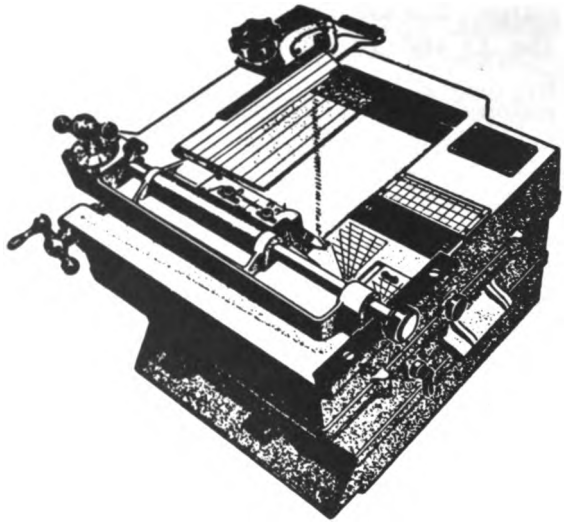


Figure 16–16.—A sonar range recorder.

petty officer does the firing. In stern attacks he gives the signal to fire.

Sound-powered telephones and an intercommunication system are provided for use between the UB plot, sonar control room, conning station, and CIC for continuous interchange of information. The members of the ASW team in UB plot are:

1. ASW control officer (mans attack director).
2. Horizontal range recorder operator.
3. Attack-plotter operator.
4. Firing petty officer.

Those in the sonar control room are:

5. Scanning sonar equipment operator.
6. Sonar range recorder operator.
7. Sonar depth-determining equipment operator.
8. Sonar supervisor.

On the bridge:

9. Helmsman.
10. Officer of the deck.

Digitized by Google

Other stations concerned:

11. CIC crew.
12. Mount captain and mount crew.
13. Depth-charge release crew.

DEFINITIONS

Symbol	Name or quantity	Definition
q----	Standard symbol modifier.	Used to indicate values measured with respect to the line of sound.
	Line of sound-----	As used in this publication and definitions, is an imaginary line extending from the sonar transducer along the sound-beam path. It deviates from a straight line by the amount of refraction in the sound beam, due to temperature, salinity, and pressure gradients present in the water medium through which the sound travels.
	Sonar transducer--	The device which transmits and receives underwater sound.
Bq------	True sonar bearing.	The angle between north and the vertical plane through the axis of the sound beam at the sonar transducer, measured in a horizontal plane clockwise from north.
cBq------	Generated true sonar bearing.	Generated by the attack director as opposed to observed true sona bearing.
Brq------	Relative sonar bearing.	The angle between the vertical plane through the fore-and-aft axis of own ship and the vertical plane through the axis of the sound beam at the sonar transducer, measured in a horizontal plane clockwise from own-ship bow.
cBrq-----	Generated relative sonar bearing.	Generated by the attack director as opposed to observed relative sonar bearing.

Digitized by Google

Symbol	Name or quantity	Definition
$\Delta cBrq$----	Increments of generated relative sonar bearing.	
cCo------	Own-ship course order.	The compass course along which own ship must be steered to intercept the target effectively.
jCo------	Own-ship course correction.	The computed angle by which own ship must change its course in order to proceed on the correct course to steer. $Co+jCo=cCo$.
Hq------	Target depth-----	The computed vertical distance, in feet, from the surface of the water to the middle of the target at the time of explosion.
Kh------	Horizontal base line.	The distance measured in yards along the fore-and-aft axis of own ship, from the sonar transducer to the depth-charge racks. A quantity used only for stern-dropped attacks.
Re-------	Effective range----	The distance in yards, traveled by a charge, from the projector-charge rack to the point at which the missile strikes the water. A quantity used only for ahead-thrown attacks.
Rq------	Sonar range-------	The distance in yards from the sonar transducer to the target, measured along the path of the sound beam.
cRq------	Generated sonar range.	Generated by the attack director as opposed to observed sonar range.
dRq------	Sonar range rate--	The time rate of change in sonar range.
Rqj------	Sonar range correction.	Manual correction to sonar range.
Rhq------	Horizontal sonar range.	The projection of sonar range Rq on a horizontal plane.
$cRhq$-----	Generated horizontal sonar range.	Horizontal sonar range, generated by the attack director.
$\Delta cRhq$----	Increments of generated horizontal sonar range.	
$dRhq$----	Horizontal sonar range rate.	The time rate of change of horizontal sonar range.

Digitized by Google

Symbol	Name or quantity	Definition
*Rhd*_____	Depth-charge explosion range.	At the time of explosion, the computed horizontal range in yards between the sonar transducer and the point of explosion.
*Sd*_____	Sinking rate_____	The speed, in feet per second, at which the charge sinks through the water.
*Td*_____	Sinking time_____	The time, in seconds, from the instant the charge strikes the water until thei nstant the explosion should occur.
*Tf*_____	Time of flight_____	The time, in seconds, from the instant the charge is fired until it strikes the water. Since this is the time during which the charge is in the air, the quantity is used only for ahead-thrown attacks.
*Tg*_____	Dead time_____	A predetermined time interval between will to fire and actual firing.
*Tu*_____	Time to explosion_	At any instant, the time remaining until the charge should explode; for pattern charges, the time remaining until the center charge should explode.
*Tud*_____	Time to fire_____	At any instant, the time remaining until the charge is to be fired.
*Xtj*_____	Correction to horizontal deflections component of target velocity.	Manual correction to *Xt*.
*Ytj*_____	Correction to horizontal range component of target velocity.	Manual correction to *Yt*.
*jXt*_____	Automatic correction to horizontal deflection component.	Automatic correction to *Xt*.
*jYt*_____	Automatic correction to horizontal range component.	Automatic correction to *Yt*.

Digitized by Google

QUIZ

1. In the sequence of actions during an underwater attack, which of the following items is given out of order?
   (*a*) Hold contact with the submarine.
   (*b*) Classify the sonar contact as a submarine.
   (*c*) Carry out an attack with either depth charges or ahead-thrown projectiles.
   (*d*) Regain contact.
   (*e*) Reattack.
2. The most common type of detonator used to explode the tear-drop or bomb-shaped depth charge is
   (*a*) magnetic.
   (*b*) acoustic.
   (*c*) hydrostatic.
   (*d*) impact.
3. Modern submarines are built so ruggedly that the lethal distance of an exploding depth charge from the pressure hull is
   (*a*) 3 yards.
   (*b*) 6 yards.
   (*c*) 12 yards.
   (*d*) 24 yards.
4. The distracting type of depth charge pattern
   (*a*) is employed to cause the submarine to surface or dive too fast.
   (*b*) is carefully calculated to sink the submarine.
   (*c*) affords "spotting" by sonar.
   (*d*) is used to harass the submarine causing its torpedo fire to be inaccurate.
5. The 7.2 inch ahead-thrown rocket has a range, from the firing point to the point where it strikes the water, of
   (*a*) 200 yards.
   (*b*) 300 yards.
   (*c*) 400 yards.
   (*d*) 500 yards.
6. During an ahead-thrown attack the Sonarman holds contact with the submarine while the conning officer keeps the ship headed toward the target at a speed not exceeding
   (*a*) 5 knots.
   (*b*) 10 knots.
   (*c*) 15 knots.
   (*d*) 20 knots.

Digitized by Google

7. The two main quantities solved for by the UWFC system are
   (*a*) *Co* and *Tg*.
   (*b*) *Xt* and *Yt*.
   (*c*) *cCo* and *Tud*.
   (*d*) *A* and *jCo*.
8. When the correction *jXt* must be applied, which one of the following quantities will always be in error?
   (*a*) *dRhq*.
   (*b*) *RdBsq*.
   (*c*) *So* cos *Br*.
   (*d*) *S* cos *A*.
9. Which of the following quantities is corrected directly by the *Yt* generation mechanism?
   (*a*) *So* cos *Br*.
   (*b*) *ΔcBrq*.
   (*c*) *dRhq*.
   (*d*) *RdBsq*.
10. By reference to figure 16–8, target speed *S* may be solved by the following formula:
   (*a*) $\sqrt{Xt^2+Yt^2}$.
   (*b*) arc tan $\frac{Xt}{Yt}$.
   (*c*) $\sqrt{Yt^2+Xt\ Tw^2}$.
   (*d*) arc tan $\frac{Yt}{Xt}$.
11. In the ahead-thrown attack, which of the following quantities is zero?
   (*a*) *Re*.
   (*b*) *Kh*.
   (*c*) *SoTd*.
   (*d*) *SoTf*.
12. Where depth-determining sonar equipment is not available, the depth set into the attack plotter is
   (*a*) estimated.
   (*b*) calculated.
   (*c*) "spotted on" by noting the echos.
   (*d*) generated.
13. Which of the following quantities cannot be read directly from the course-order dial of the attack plotter discussed in the text?
   (*a*) Own ship's course (*Co*).
   (*b*) Relative bearing (*Brq*).
   (*c*) Own ship's course order (*cCo*).
   (*d*) True target bearing (*Bq*).

Digitized by Google

14. The position of the bug on the target course and speed dial of the attack director represents the
    (*a*) conning tower of the submarine.
    (*b*) direction for own ship to steer.
    (*c*) future target position.
    (*d*) bow of the submarine.
15. Motion of the target acceleration bug indicates
    (*a*) that the generated quantities are in error.
    (*b*) a change in sonar range.
    (*c*) that the attack plotter is nearing solution.
    (*d*) changes of target speed, independent of all other quantities.

Digitized by Google

APPENDIX I

ANSWERS TO QUIZZES

CHAPTER 2

BALLISTICS AND TABLES

1. (*d*) The angle of impact is always equal to the angle of fall.
2. (*c*) Travels only a limited distance due to air resistance.
3. (*d*) Projectile ogive.
4. (*b*) The projectile speed decreases toward the end of the trajectory.
5. (*c*) 45°.
6. (*a*) 16-inch.
7. (*c*) Quadruples.
8. (*b*) The striking velocity is less than the *I.V.*
9. (*a*) Temperature and barometer scales.
10. (*c*) Erosion.
11. (*b*) 65 ft./sec.
12. (*d*) Minus 20 ft./sec.
13. (*e*) Erosion error.

CHAPTER 3

MECHANICAL MULTIPLIERS

1. (*c*) Similar triangles.
2. (*a*) The pivot arm is directly in line with the output rack.
3. (*a*) Shift the position of the stationary pin.
4. (*b*) Multiplier pin is directly over the stationary pin.
5. (*c*) Both input racks No. 1 and No. 2 are at zero.
6. (*c*) Any value.
7. (*d*) Both negative and positive inputs.
8. (*b*) Have no effect.
9. (*a*) Rack-type.
10. (*c*) Slide input.

Digitized by Google

CHAPTER 4

COMPONENT AND VECTOR SOLVERS

1. (*c*) Ship's speed.
2. (*a*) Horizontal.
3. (*c*) Zero.
4. (*a*) Compensating differential.
5. (*a*) Angle input before speed input.
6. (*d*) No difference.
7. (*c*) No movement occurs on either slide when the angle gear is rotated.
8. (*d*) Screw.
9. (*a*) The screw loses motion through long usage.
10. (*a*) Cam-type component solver.
11. (*d*) Course and speed.
12. (*a*) Using the outputs as inputs and checking for movement of the input slides.
13. (*b*) Target course only.
14. (*d*) Small electric follow-up motors.

CHAPTER 5

MECHANICAL INTEGRATORS

1. (*d*) Continuously add small changes to give the total change.
2. (*a*) Yards per second.
3. (*a*) Change in range.
4. (*b*) Continuous present range.
5. (*c*) Time and range rate.
6. (*d*) Total change in range.
7. (*b*) Time.
8. (*a*) Zero.
9. (*b*) Roller.
10. (*c*) Reverses rotation.
11. (*a*) Output roller remains stationary when range rate is zero.
12. (*a*) Angle input.
13. (*a*) Zero.

CHAPTER 6

FIRE CONTROL GYROSCOPES

1. (*c*) Gyroscopic stability.
2. (*a*) Forces which tend to tilt the gyro wheel.
3. (*d*) Gyroscopic stability.

Digitized by Google

4. (*b*) Tilt to the west.
5. (*b*) 15°.
6. (*c*) Equator.
7. (*a*) North pole.
8. (*b*) Correct positions for any latitude.
9. (*d*) Counteract the westward tilt of the gyro.
10. (*a*) North.
11. (*a*) Mercury ballistic tanks and gimbal rotation.
12. (*c*) Gyro erection system.
13. (*c*) Amount of precession.
14. (*c*) Momentum of the spinning wheel and the applied force.
15. (*b*) Rotated at the same constant speed.

CHAPTER 7

LINKAGE COMPUTING MECHANISMS

1. (*d*) They can be designed to be nonresonant below the critical frequency of 60 cycles.
2. (*c*) slide bar.
3. (*b*) properly locating the output link on the adding and subtracting bar.
4. (*a*) It has a tubular rod having right-hand threads at each end.
5. (*c*) rock the pivoted roller blocks.
6. (*d*) lever multiplier.
7. (*d*) using the same arrangement as is used for addition.
8. (*a*) $y=\frac{xa}{b}$
9. (*b*) bell crank and lever multiplier.
10. (*a*) *a*.
11. (*a*) exchanging the output with either input.
12. (*c*) two lever multipliers.
13. (*c*) $y=x$ ($\frac{2}{4}\times\frac{4}{6}$).
14. (*d*) 90° apart.
15. (*d*) a planitary gearing arrangement.

CHAPTER 8

ELECTRO-MECHANICAL SERVO MECHANISMS

1. (*a*) The capacitor in series with one winding or the other.
2. (*b*) The servo rotor.
3. (*c*) The heavy steel ring is laminated.
4. (*f*) Differential.

Digitized by Google

5. (*e*) Servo rotor.
6. (*g*) Servo motor.
7. (*c*) Side gear.
8. (*a*) Outer servo contacts.
9. (*d*) The spider gear positions the inner servo contact arm.
10. (*c*) The intermittent gearing improves the dynamic accuracy.
11. (*b*) Inner servo contact arm.
12. (*a*) It damps the outer contacts.
13. (*a*) Improves the dynamic accuracy.
14. (*a*) The rotor is driven by the response of the follow-up motor.
15. (*c*) Magnetic drag damps the inner contacts.
16. (*d*) 18 times.
17. (*d*) 17.5 yards.
18. (*d*) Differential spider.
19. (*b*) Upper contacts on the scissor arms.
20. (*c*) Coarse control contacts are near centralization.

CHAPTER 9

SOLVING WIND CORRECTIONS

1. (*b*) Ballistic wind.
2. (*a*) Vertical wind.
3. (*c*) Advance range.
4. (*d*) $Sw \times Tf \times K \times 0.563$.
5. (*b*) *Cws*.
6. (*c*) $(B+180)-Cw$.
7. (*a*) Component solver.
8. (*d*) *Xw*.
9. (*b*) *Cws*.
10. (*b*) end of trajectory.
11. (*c*) $\frac{1}{1{,}000}$.
12. (*c*) 0.563.

CHAPTER 10

THE RELATIVE MOTION PROBLEM

1. (*d*) *Vs*.
2. (*b*) *Ds*.
3. (*c*) *So* by sin *Br*.
4. (*b*) *Xo* and *Yo*.
5. (*a*) *Xt* and *Yt*.
6. (*a*) The vector input from changing when the angle gear is rotated.

Digitized by Google

7. (*c*) dR.
8. (*b*) $RdBs$.
9. (*b*) $R2$.
10. (*d*) $\frac{RdBs \times Tf}{R2}$
11. (*a*) —10 knots.
12. (*c*) Across the line of sight.
13. (*c*) Dt, Dw, and Df.
14. (*d*) $R2$.
15. (*h*) None of the above.

CHAPTER 11

DECK AND TRUNNION TILT

1. (*b*) The deck is level.
2. (*a*) Line of sight.
3. (*d*) $B'r'$ and $jB'r'$.
4. (*d*) $B'r'$.
5. (*c*) Both the level and cross-level gimbals are level.
6. (*a*) Drive the same amount into the rangekeeper.
7. (*a*) In and across the LOS.
8. (*b*) Negative.
9. (*b*) Negative.
10. (*d*) Deck plane.
11. (*a*) Increase as Vs increases.
12. (*c*) Vs, Ds, L', and Zh.
13. (*a*) cam outputs.
14. (*c*) $B'r'$.
15. (*d*) single-cam computing multiplier.
16. (*b*) Multiplier.

CHAPTER 12

THE GUN ORDERS

1. (*a*) $B'r'$.
2. (*b*) L'.
3. (*d*) Director train and range.
4. (*b*) The stable vertical fails.
5. (*c*) $B'r'$, Ds, and Dz.
6. (*a*) Ahead or astern.
7. (*d*) Range.
8. (*b*) $Ph = \frac{b}{R} \sin B'gr$.

Digitized by Google

9. (*a*) So that all guns and directors can be alined to the same point.
10. (*d*) $\frac{1}{R}$.
11. (*a*) Transmitted director train angles are equal.
12. (*b*) *Vs*, *Vz*, and *L'*.
13. (*c*) *L'*.
14. (*a*) Reference plane.
15. (*d*) Reference point.

CHAPTER 13

GENERATED RATES

1. (*b*) *cR*.
2. (*a*) $jR+\Delta cR$.
3. (*c*) *dR* and *T*.
4. (*a*) Total change in present range.
5. (*c*) Time rate for change of present range.
6. (*d*) Zero.
7. (*b*) Increasing.
8. (*a*) Decreasing.
9. (*a*) Accumulates the products of *dR* and time.
10. (*d*) *cB*.
11. (*c*) *cBr*.
12. (*b*) $Br-cBr$.
13. (*a*) Target angle or target speed is in error.
14. (*d*) $\Delta cB+Co+jB'r'$.

CHAPTER 14

RANGEFINDERS

1. (*c*) tangent.
2. (*c*) tangent.
3. (*a*) $206{,}265\frac{BM}{R}$
4. (*d*) 95 times.
5. (*a*) their magnifying power.
6. (*b*) cancels the vertical refraction.
7. (*d*) the glass is slightly wedge shaped, forming a prism.
8. (*d*) rhomboid prisms.
9. (*d*) parallel.
10. (*a*) through alternately open end ports.
11. (*c*) correction wedge.
12. (*d*) arbitrary units.
13. (*d*) 12 seconds.
14. (*a*) yards.

Digitized by Google

15. (*b*) squared.
16. (*c*) halved.
17. (*a*) doubled.
18. (*d*) Blake (30-ft. 12X rangefinder) : range 35,000, error 1,200.
19. (*b*) units of adjuster scale.
20. (*b*) units of adjuster scale.

CHAPTER 15

TORPEDO FIRE CONTROL

1. (*a*) Compressed air.
2. (*d*) 22½ inches.
3. (*d*) 47 knots.
4. (*b*) 16,000.
5. (*d*) Air flask.
6. (*d*) a spring tension.
7. (*d*) water pressure.
8. (*a*) LOS.
9. (*c*) torpedo depth.
10. (*c*) difference between the latitudes.
11. (*b*) 0.042.
12. (*b*) 0.84° left.
13. (*d*) Own ship speed.
14. (*c*) latitude 00 degrees.
15. (*a*) setting in a latitude correction *Kla* at the director.
16. (*b*) Target run in yards, torpedo run in yards, and the line of sight.
17. (*b*) *Kla* plus *Osi*.
18. (*b*) Intercept offset, *Osi*.
19. (*a*) *Ds*.

CHAPTER 16

UNDERWATER FIRE CONTROL

1. (*a*) and (*b*) are reversed.
2. (*c*) hydrostatic.
3. (*b*) 6 yards.
4. (*d*) is used to harass the submarine causing its torpedo fire to be inaccurate.
5. (*a*) 300 yards.
6. (*b*) 10 knots.
7. (*c*) *cCo* and *Tud*.

Digitized by Google

8. (*b*) ***RdBeq.***
9. (*c*) ***dRhq.***
10. (*a*) $\sqrt{Xt^2+Yt^2}$.
11. (*b*) ***Kh.***
12. (*a*) **estimated.**
13. (*b*) **Relative bearing (*Brq*).**
14. (*d*) **bow of the submarine.**
15. (*a*) **that the generated quantities are in error.**

Digitized by Google

APPENDIX II
SURFACE FIRE CONTROL SYMBOLS

To simplify references to the various quantities involved in the fire control problem, and to parts of the rangekeeper concerned with the respective quantities, the system of nomenclature given below has been adopted. This system of nomenclature complies with O.D. 3447, STANDARD FIRE CONTROL AND TORPEDO CONTROL SYMBOLS. The fire control symbols defined below should not be confused with the letters *A*, *D*, *L* and *B*, followed by numbers, which are used to designate adjustment points, differentials, limit stops and electrical reversing switches, respectively.

In the definitions given below the following terms are understood:

(*a*) The term "line of sight" is used to designate the line of sight from the director to the target.

(*b*) The term "deck plane" means the horizontal reference plane of the ship.

(*c*) The term "the horizontal plane" refers to the horizontal plane through the director sights. The solution given by the rangekeeper is based upon this plane.

Symbol	*Definition*
A	*Target angle.* — Angle between vertical plane through fore and aft axis of target and vertical plane through line of sight, measured in the horizontal plane clockwise from bow of target. ($A = 180° + cB - Ct$)
cB	*Generated true target bearing.* — Generated angle between north-south vertical plane and vertical plane through line of sight, measured in the horizontal plane clockwise from north. ($cB = \Delta cB + jB$)
ΔcB	*Increments of generated true target bearing.*
jB	*Initital or corrective setting to generated target bearing.*
Br	*Relative target bearing.* — Angle between vertical plane through fore and aft axis of ship and vertical plane through line of sight, measured in the horizontal plane clockwise from bow. ($Br = B'r' + jB'r'$)
cBr	*Generated relative target bearing.* — Relative target bearing generated by rangekeeper as opposed to relative target bearing derived from director train. ($cBr = cB - Co$)
Bw	*Wind direction.* — Angle between north-south vertical plane and direction from which true wind is blowing, measured in the horizontal plane clockwise from north.

Digitized by Google

Symbol	Definition
$B'gr$	*Gun train order.* — Ordered angle between fore and aft axis of ship and plane through gun axis perpendicular to deck plane, measured in deck plane clockwise from bow, without parallax correction. ($B'gr = B'r' + Dd'$)
$B'r'$	*Director train.* — Angle between fore and aft axis of ship and plane through line of sight perpendicular to deck plane, measured in deck plane clockwise from bow.
$cB'r'$	*Generated director train.* — Director train as generated by rangekeeper. ($cB'r' = cBr - jB'r'$)
$\Delta oB'r'$	*Increments of generated director train.* (Bearing correction.)
$jB'r'$	*Correction to director train for effect of deck tilt.* (Refers director train to the horizontal plane.)
Co	*Ship course.* — Angle between north-south vertical plane and vertical plane through fore and aft axis of ship, measured in the horizontal plane clockwise from north.
Ct	*Target course.* — Angle between north-south vertical plane and vertical plane through direction of target motion, measured in the horizontal plane clockwise from north.
Cws	*Wind angle* — Angle between direction toward which true wind is blowing and vertical plane through line of sight, plus 180°, measured in the horizontal plane clockwise from direction toward which wind is blowing. ($Cws = 180° + cB - Bw$)
Dd'	*Deck deflection.* — Angle representing total deflection in deck plane; equal to gun train order minus director train. ($Dd' = Ds + Dz$)
Df	*Deflection to compensate for drift of projectile.* (Measured in the horizontal plane.)
Dj	*Deflection correction.* (Includes spots and ballistic corrections.)
Ds	*Sight deflection.* — Angle between vertical plane through line of sight and vertical plane through gun axis (neglecting parallax), measured in the horizontal plane. (Positive, if gun is trained right from line of sight.) (This is an approximation of sight deflection as defined in O.D. 3447.) ($Ds = Dtwj + Df$)
Dt	Deflection to compensate for relative movement of ship and target. ($Dt = jDt + KRdBs$)
jDt	Partial deflection to compensate for relative movement of ship and target. [$jDt = RdBs(Tf/Rs - K)$]
Dw	Deflection to compensate for effect of apparent wind on projectile.

Digitized by Google

Symbol	*Definition*
Dtw	*Dt + Dw.*
Dtwj	*Dtw + Dj.*
Dz	*Trunnion-tilt train correction.* — Approximate correction in gun train order to compensate for tilting of gun trunnions in cross-level. (Also refers sight deflection to deck plane.)
E'g	*Gun elevation order.* — Ordered elevation of gun above deck plane, measured in plane through gun axis perpendicular to deck plane, without parallax correction. (*E'g = L' + Vs + Vz*)
I.V.	*Initial velocity.*
K, K1, K2, etc.	*Constants.* — Two or more constants in same expression are distinguished by numbers.
L'	*Level angle.* — Angle between the horizontal plane and deck plane, measured in plane perpendicular to deck plane containing line of sight. (Positive, when deck toward target is tilted down.)
P.C.	*Powder charge.*
cR	*Generated present range.* (*cR = jR + ΔcR*)
$\frac{1}{cR}$	*Inverse generated present range.*
ΔcR	*Increments of generated present range.*
dR	*Range rate.* (*dR = Yo + Yt*)
jR	*Initial or corrective setting to generated present range.*
RdBs	*Deflection rate.* — Linear bearing rate measured at target. (*RdBs = Xo + Xt*)
Rj	*Range correction.* — (Includes spots and ballistic corrections.) (Affects advance range only.)
Rm	*Range prediction to compensate for changes from initial velocity.*
jRm	*Partial range prediction to compensate for changes from initial velocity.*
Rt	*Range prediction to compensate for relative movement of ship and target.*
Rw	*Range prediction to compensate for effect of apparent wind on projectile.*
Rtw	*Rt + Rw.* (*Rtw = jRtw + K1Ywr*)
jRtw	*Partial Rtw.* [*jRtw = Tf(dR − KYwr)*]
Rx	*Range prediction to compensate for deflection.* (Exclusive of drift.)
jRx	*Partial range prediction to compensate for deflection.* (Exclusive of drift.)
Rmx	*Rm + Rx.*
jRmx	*jRm + jRx.*

Digitized by Google

Symbol	*Definition*
Rtwmx	*Rtw* + *Rmx*.
Rjtwmx	*Rj* + *Rtw* + *Rmx*.
Rℓ	*Advance range*. (*Rℓ* = *cR* + *Rjtwmx*)
S	*Target speed*.
So	*Ship speed*.
Sw	*True wind speed*.
T	*Time*. (Generated by regulated time motor.)
Tf	*Time of flight*. (*Tf* = *jTf* + *KRℓ*)
jTf	*Partial time of flight*. (Cam output.)
Tf/Rℓ	*Time of flight divided by advance range*.
Vs	*Sight angle*. — Angle between gun axis and the horizontal plane (neglecting parallax), measured in vertical plane through gun axis. (Positive, if axis of gun points above the horizontal plane.) (This is an approximation of sight angle as defined in O.D. 3447.) (*Vs* = *jVs* + *KRℓ*)
jVs	*Partial sight angle*. (Cam output.)
Vz	*Trunnion-tilt elevation correction*. — Correction in gun elevation order to compensate for cross-level.
Xo	*Component of ship velocity across line of sight*. (*Xo* = *So* sin *cBr*)
Xt	*Component of target velocity across line of sight* (*Xt* = *S* sin *A*)
Xw	*Component of true wind velocity across line of sight*. (*Xw* = −*Sw* Sin *Cws*)
Xwr	*Component of apparent wind velocity across line of sight*. (*Xwr* = *Xo* + *Xw*)
Yo	*Component of ship velocity along line of sight*. (*Yo* = −*So* cos *cBr*)
Yt	*Component of target velocity along line of sight*. (*Yt* = −*S* cos *A*)
Yw	*Component of true wind velocity along line of sight*. (*Yw* = *Sw* cos *Cws*)
Ywr	*Component of apparent wind velocity along line of sight*. (*Ywr* = *Yo* + *Yw*)
Zh	*Cross-level angle*. — Angle between vertical plane through line of sight and plane perpendicular to deck plane containing line of sight; dip angle effect being neglected. (Positive if, when facing target, deck at left is tilted down.)

Digitized by Google

APPENDIX III

QUALIFICATIONS FOR ADVANCEMENT IN RATING

FIRE CONTROL TECHNICIANS (FT)

RATING CODE NO. 0800

SCOPE

General Service Rating

Fire control technicians are highly skilled technicians assigned to combatant vessels, repair ships, and repair facilities, who operate fire control equipment, including range finders, computers, fire control radars, directors, switchboards, and associated units aboard naval vessels, and make detailed casualty analysis, major repair, and overhaul to fire control systems, including fire control radar.

Emergency Service Rating

Same as General Service Rating.

Navy Job Classifications and Codes

For specific Navy job classifications included within this rating and the applicable job codes, see Manual of Enlisted Navy Job Classifications, NavPers 15105 (Revised), codes FT–1100 to FT–1199.

Qualifications for Advancement in Rating

Qualifications For Advancement in Rating	*Applicable Rates*
	FT
100 PRACTICAL FACTORS	
101 OPERATIONAL	
1. Demonstrate method of resuscitating a man unconscious from electrical shock, and treating for electrical burns	3
2. Identify electrical and mechanical symbols used in schematic diagrams of fire control equipment, excluding radar	3

Digitized by Google

Qualifications For Advancement in Rating	*Applicable Rates*
	FT
101 OPERATIONAL—continued	
3. Read dials and set operating controls to predetermined values on fire control equipment	3
4. Use RMA color codes for capacitors and resistors	3
5. Demonstrate on fire control equipment to which assigned, operating procedures and techniques as required to:	
a. Perform operator's adjustments	3
b. Perform transmission, computing, and rate tests	2
6. Identify electronic symbols used in schematic diagrams of fire control equipment	2
7. Demonstrate operating procedures and techniques on fire control system to which assigned, as required to train battle station and watch standing operators	C
8. Compute corrections to compensate for operator and range-finder errors	C
9. Compute initial ballistics correction using standard forms and work sheets	C
102 MAINTENANCE AND/OR REPAIR	
1. Lubricate fire control equipment in accordance with lubrication charts	3
2. Conduct shipboard tests of lead computing sights	3
3. Make tests of electrical fire control circuits for continuity, grounds, and short circuits. Make electrical repairs	3
4. Inspect and clean commutator and slip ring assemblies and replace brushes	3
5. Make operator's adjustments and checks to fire control radars	3
6. Make prescribed electronic tests of servo and computing circuits using multimeters, tube testers, and cathode ray oscilloscopes and report results	2
7. Conduct transmission, computing, and rate tests on fire control equipment and report or record results	2

Digitized by Google

	Qualifications For Advancement in Rating	*Applicable Rates*
		FT
102	MAINTENANCE AND/OR REPAIR—continued	
	8. Prepare a gun or director station for battery alinement afloat by alining synchros and setting mechanical dials to reference points	2
	9. Trace circuits through fire control and sound-powered telephone switchboards	2
	10. Make internal adjustments and calibrations to fire control radars	2
	11. Make prescribed electronic tests of radar circuits using signal generators, multimeters, tube testers, and cathode ray oscilloscopes and report results	2
	12. Perform all tests and adjustments necessary for proper operation of servo and computing circuits. Test synchros, interconnecting circuits, and switchboards and set synchros to electrical zero	2
	13. Conduct battery alinement tests and evaluate results	1
	14. Boresight and aline guns, directors, fire control radar antennas, and torpedo fire control equipment. Test firing cut-out devices for proper operation	1
	15. Make tests for dynamic accuracy of fire control equipment by means of a dummy director and error recorder and analyze results	1
	16. Trace circuits and test synchros and servo mechanisms and make replacements, adjustments, and repairs	1
	17. Test, remove, replace, and adjust mechanical parts of fire control and torpdeo control equipment	1
	18. Perform all tests and adjustments necessary for proper operation of radar circuits	1
	19. Analyze and make repairs to servo and computing circuits for failures	1
	20. Perform all shipboard maintenance on rangefinders not requiring the services of an opticalman	1

Digitized by Google

	Qualifications For Advancement in Rating	*Applicable Rates*
		FT
102	MAINTENANCE AND/OR REPAIR—continued	
	21. Lubricate and perform shipboard adjustments to gyroscopes used in fire control equipment	1
	22. Analyze transmission, alinement, computer, and rate tests to determine need for adjustment, replacement of parts, or repairs	C
	23. Conduct all electrical tests on a complete fire control system	C
	24. Repair mechanical parts of fire control and torpedo control equipment, excluding lathe and milling machine work	C
	25. Analyze and make repairs to radars for circuit failures	C
103	ADMINISTRATIVE AND/OR CLERICAL	
	1. Keep rough logs	3
	2. Make failure reports and keep ordnance histories	2
	3. Use Catalogue of Navy material, BuOrd Section	2
	4. Maintain a Current Ship's Maintenance Project (CSMP) and prepare naval shipyard, tender work request, or job order	C
	5. Maintain supplies and spare parts and obtain replacements	C
200	**EXAMINATION SUBJECTS**	
201	OPERATIONAL	
	1. Types of information shown and meanings of electrical and mechanical symbols used in schematic diagrams of fire control equipment, excluding radar and fire control quantities	3
	2. Interpret and interpolate a dial setting into minutes, degrees, yards, or mils	3
	3. Know the RMA color coding systems for capacitors and resistors	3
	4. Given course and speed of own ship, surface target, and true wind, solve analytically for range rate and deflection rate	3

Digitized by Google

	Qualifications For Advancement in Rating	*Applicable Rates*
		FT
201	OPERATIONAL—continued	
	5. Types of information shown and meanings of electronic symbols used on schematic diagrams of fire control equipment, excluding symbols for fire control quantities	2
	6. Given course and speed of own ship, air target, and true wind, solve analytically for range rate and deflection rate	2
	7. Operating principles of stereo rangefinders. Methods used to measure operator and rangefinder errors and methods used to compute corrections	C
	8. Variables and constants of initial ballistics	C
	9. Elements of air and surface fire control problems	C
202	MAINTENANCE AND/OR REPAIR	
	1. Precautions to be observed in lubricating fire control equipment	3
	2. Purpose and interpretation of lead computing sight tests	3
	3. Methods and equipment used in electrical tests for continuity, grounds, and short circuits	3
	4. Purposes of the following fire control radar operator's adjustments and checks: Intensity, sweep, focus, centering, receiver gain, receiver tuning, video gain, modulator frequency, range slew, range and train and elevation zero checks	3
	5. Function of each of the elements in gas-filled, vacuum, and cathode ray tubes	3
	6. Calculate current, voltage, phase angle, impedance, and resistance in series and parallel circuits containing not more than a combination of four elements	3
	7. Methods of testing resistors, potentiometers, coils, transformers, capacitors, and vacuum tubes and the application of each in voltage amplifier, phase inverter, power supply, oscillator, power amplifier, and rectifier circuits. Recognize electonic stages, power supply circuits, and coupling circuits	3

Digitized by Google

	Qualifications For Advancement in Rating	*Applicable Rates*
		FT
202	MAINTENANCE AND/OR REPAIR—continued	
	8. Purposes of transmitting, computing, and rate tests	2
	9. Use of tram bar, method of setting synchros to electrical zero, and method of positioning shafts by adjustable couplings	2
	10. Types, operating principles, and application of switching gear used in fire control and sound-powered switchboards	2
	11. Characteristics and use of synchros and methods of setting to electrical zero	2
	12. Operating principles (excluding knowledge required *only* in research, engineering, and manufacture) of the following: Tuned coupling circuits, impedance matching, cathode followers, modulators and demodulators, oscillators, phase shifters, mixers, superheterodyne receivers, automatic gain control, frequency modulation, discriminators, automatic frequency control, wave shape and transients, integration and differentiation, counting circuits, saw tooth generators, multivibrators, limiters, peakers, clampers, and half- and quarter-wave antennas	2
	13. Methods of making gain, phase, balancing, bias, and zeroing adjustments of servo loops found in computing and power drive circuits	2
	14. Method of mounting and alining a boresight telescope on a gun. Purpose and method of alining sights to gun bore. Purpose and method of checking a director to a reference plane and reference point. Quantities set on inclination compensators. Methods used to conduct train and elevation checks afloat	1
	15. Types, application, and operating principles of electromechanical servo mechanisms	1
	16. Purpose, operating principles, and adjustments of standard fire control units	1

Digitized by Google

Qualifications For Advancement in Rating	*Applicable Rates*
	FT
202 MAINTENANCE AND/OR REPAIR—continued	
17. Purpose and operating principles of the following radar circuits: Transmitter, video amplifier, modulation generator, range unit, indicator unit, echo box, dummy antenna, power supply, wave guides, antennas, voltage regulator, transmission lines, IF amplifier, RF amplifier, or preselector	1
18. Operating principles of computing and power drive circuits	1
19. Method of gassing a rangefinder	1
20. Properties of free and restrained gyroscopes and purpose of damping	1
21. Method of setting up and purpose of dummy director and error recorder tests; information obtained and interpretation of results	1
22. Methods used in battery alinement afloat and drydock. Use of gunner's quadrant. Method and purpose of static alinement. Principles involved in establishing bench mark and tram points. Method of computation of roller path inclination from horizon checks. Methods of train and elevation checks afloat	C
23. Relationship of electrical and mechanical inputs and outputs of a radar, rangefinder, director, computer, stable element, and gun mount of a dual purpose battery	C
24. Purpose and method of the following radar checks: Double echo, receiver sensitivity, standing wave ratio, and transmitted power level	C
203 ADMINISTRATIVE AND/OR CLERICAL	
1. Purposes and types of entries made in rough logs	3
2. Purposes and types of entries made in failure reports and ordnance histories	2

Digitized by Google

	Qualifications For Advancement in Rating	*Applicable Rates*
		FT
203	ADMINISTRATIVE AND/OR CLERICAL—continued	
	3. Types of information found in the following publications: OP, OD, OCL, OHI, OMI, OML, ORDALTS, and BuOrd Instructions and Notices	2
	4. Purpose and scope of the BuOrd Manual as stated in chapter I	1
	5. Information shown in Current Ship's Maintenance Project (CSMP), naval shipyard, tender work request, and job order	C
	6. Physical requirements for rangefinder operators	C

Digitized by Google

APPENDIX IV

TRIGONOMETRIC FUNCTIONS OF AN ANGLE

Angle	Sin	Cos	Tan	Cot	Sec	Csc	
0°	0. 0000	1. 0000	0. 0000	∞	1. 000	∞	90°
1	. 0174	. 9998	. 0175	57. 29	1. 000	57. 30	89
2	. 0349	. 9994	. 0349	28. 64	1. 001	28. 65	88
3	. 0523	. 9986	. 0524	19. 08	1. 001	19. 11	87
4	. 0698	. 9976	. 0699	14. 30	1. 002	14. 34	86
5	. 0872	. 9962	. 0875	11. 43	1. 004	11. 47	85
6	. 1045	. 9945	. 1051	9. 514	1. 006	9. 567	84
7	. 1219	. 9925	. 1228	8. 144	1. 008	8. 206	83
8	. 1392	. 9903	. 1405	7. 115	1. 010	7. 185	82
9	. 1564	. 9877	. 1584	6. 314	1. 012	6. 392	81
10	. 1736	. 9848	. 1763	5. 671	1. 015	5. 759	80
11	. 1908	. 9816	. 1944	5. 145	1. 019	5. 241	79
12	. 2079	. 9781	. 2126	4. 705	1. 022	4. 810	78
13	. 2250	. 9744	. 2309	4. 331	1. 026	4. 445	77
14	. 2419	. 9703	. 2493	4. 011	1. 031	4. 134	76
15	. 2588	. 9659	. 2679	3. 732	1. 035	3. 864	75
16	. 2756	. 9613	. 2867	3. 487	1. 040	3. 628	74
17	. 2924	. 9563	. 3057	3. 271	1. 046	3. 420	73
18	. 3090	. 9511	. 3249	3. 078	1. 051	3. 236	72
19	. 3256	. 9455	. 3443	2. 904	1. 058	3. 072	71
20	. 3420	. 9397	. 3640	2. 747	1. 064	2. 924	70
21	. 3584	. 9336	. 3839	2. 605	1. 071	2. 790	69
22	. 3746	. 9272	. 4040	2. 475	1. 079	2. 669	68
23	. 3907	. 9205	. 4245	2. 356	1. 086	2. 559	67
24	. 4067	. 9135	. 4452	2. 246	1. 095	2. 459	66
25	. 4226	. 9063	. 4663	2. 145	1. 103	2. 366	65
26	. 4384	. 8988	. 4877	2. 050	1. 113	2. 281	64
27	. 4540	. 8910	. 5095	1. 963	1. 122	2. 203	63
28	. 4695	. 8829	. 5317	1. 881	1. 133	2. 130	62
29	. 4848	. 8746	. 5543	1. 804	1. 143	2. 063	61
30	. 5000	. 8660	. 5774	1. 732	1. 155	2. 000	60
31	. 5150	. 8572	. 6009	1. 664	1. 167	1. 942	59
32	. 5299	. 8480	. 6249	1. 600	1. 179	1. 887	58
33	. 5446	. 8387	. 6494	1. 540	1. 192	1. 836	57
34	. 5592	. 8290	. 6745	1. 483	1. 206	1. 788	56
35	. 5736	. 8192	. 7002	1. 428	1. 221	1. 743	55
36	. 5878	. 8090	. 7265	1. 376	1. 236	1. 701	54
37	. 6018	. 7986	. 7536	1. 327	1. 252	1. 662	53
38	. 6157	. 7880	. 7813	1. 280	1. 269	1. 624	52
39	. 6293	. 7771	. 8098	1. 235	1. 287	1. 589	51
40	. 6428	. 7660	. 8391	1. 192	1. 305	1. 556	50
41	. 6561	. 7547	. 8693	1. 150	1. 325	1. 524	49
42	. 6691	. 7431	. 9004	1. 111	1. 346	1. 494	48
43	. 6820	. 7314	. 9325	1. 072	1. 367	1. 466	47
44	. 6947	. 7193	. 9657	1. 036	1. 390	1. 440	46
45	. 7071	. 7071	1. 0000	1. 000	1. 414	1. 414	45
	Cos	Sin	Cot	Tan	Csc	Sec	Angle

Digitized by Google

Digitized by Google

INDEX

A-curve, constructing, 367
Absoluter linkage mechanism, 157
Ahead-thrown attack(s)
  problem, 421
  solution for, 421
  weapons for, 411
Air density, 27
  nomogram, 31
Air in motion, 199
Air trajectory, 23
Angle input, 105
Angle of departure, 20
Angle resolver, 163
  compensated, 165–168
Antiaircraft battery control, 12
Antisubmarine warfare, 405
Apparent wind, 237
Attack, types, 415
Attack director, 426, 428, 433
  face of, 428
  function, 427
  operation of, 430
Attack plotter, 427, 433
Attack problem
  geometry of, 416
  progression of, 416
Automatic inputs, 427
Automatic outputs, 429

B-curve, constructing, 367
Balance nut positions, 384
  corrected, 385
Ball-and-roller-type integrator, 97
Ballistic cam, 35
Ballistic computer, 246
Ballistic density, 30
Ballistic wind, 200
Ballistics
  exterior, 17
  interior, 17
Basic sight angle, 393
  corrections to, 394
Battery control, 12
Battery control officer, 12
Battery plotting room, 251
Battle bill, 6
Bearing mounted synchro, 185
Bell crank multiplier, 151–152

Cam
  ballistic, 35
  correction, 245
  follower, 67
Cam-type component solver, 65
  adjustment, 73
  computing, 77
Combat information center, function, 9–10
Communications, 14
Compensated angle resolver, 165
  construction, 167
Compensated follow-up control, 182
Compensating differential, 71–72
Compensator mechanism, 183
Component integrator, 101, 105, 110
  adjusting, 109
  construction, 104
Component solver(s), 63
  offset pin, 82–84
  own ship's, 73
  screw-type, 78
  adjusting, 82
Corrected sight angle, 393
Correction wedge, 354
Cross level, 252
  correcting, 256
  effect of with sight deflection present, 284
  measuring, 261
  surface problem, 279
Cross level angle after measurement, 262
Cross level error, 262
Cross leveler's periscope, 266
Cross wind, 201
  deflection correction, 201

Deck deflection, 285
Deck tilt computations, 289
Deck tilt computer, 271
Deck tilt correction, 251, 267
  computing, 269
Deflection components, 226
Deflection prediction, 230

Digitized by Google

Depth charge patterns, 407
destructive, 407
distracting, 407
Depth charges, 406
Depth mechanisms, 382
Destroyer torpedo directors, 388
Director elevation 264, 307
Director indexing diagram, 386
Director parallax, 303
Director train, increments of, 327
Drift
causes of, 38
effect of, 37

Electric torpedo, 387
Electro-mechanical servo mechanisms, 173
End reflectors, 351
Equator, apparent rotation at, 123
Exterior ballistics, 17

Fire control
gyroscopes, 113
organization, 7
symbols, surface, 449–452

Generated bearing, 325
Generated mechanism, Mk 8 rangekeeper, f. p. 332
Generated present range, 317, 323–324
Generated rates, solution of, 424
Generated relative target bearing, 325
Gimbal mounted gyro, 115
Gimbal mounting, 115
Gimbal ring, 115
Gimbal rotation, 121
Graphic plotter operator, 365
Group control officer, 13
Gun elevation, how affected by level, angle, 273
Gun elevation order, 305
Gun position, how cross level affects, 274
Gun range, finding, 34
Gun train order, 298
Gunnery department, 4
Gunnery officer, duties, 11
Gyro angle, 389
Gyro mechanisms, 382
Gyro mounting, rate-of-turn, 129
Gyroscope(s)
apparent rotation at the equator, 123
correction weight, 125
Gyroscope(s)—Continued
effect of earth's rotation at mid-latitudes, 126
effect of friction, apparent rotation and latitude, 118
fire control, 113
free, 116
gimbal rotation, 121
latitude correction, 124
precession, 116
rate-of-turn, 128
stable vertical, 119, 127
Gyroscopic stability, 114

Horizontal parallax with target abeam, 300

Index correction, 365
Initial bearing, 325
Initial velocity, 17
Integration, 93
Integrator
ball-and-roller, 97
basic, 94–98
component, 101
Integrator action, 99
Integrator carriage, adjusting, 100
Interior ballistics, 17
Intermittent gearing, 178
Internal adjuster correction wedge, 354
Inverse range, 308

Latitude correction, 383
Level
correcting, 256
effect of on trunnion tilt, 285
Level angle, 252
after measurement, 261
Level error, 260
Lever multiplier, 150
Line of departure, 20
Linear deflection, 226
Linear four-bar linkage, 160
Linear range rate, 226
Linear rates, 226
Link connections, 141
Linkage arrangement, 163
Linkage computer, 139
Linkage computing mechanisms, 137
Linkages, adding with, 145
Links, adjustable, 142

Magnetic damper cut-away view, 175

Digitized by Google

Magnetic drag, 179
cut-away view, 181
Manual inputs, 429
Mean torpedo course, 389
Measuring wedge, 345
effect of rotation, 347
operation of, 346
Mk 8 rangekeeper, generating mechanism, f. p. 332
Mount captains, 14
Multiplier(s)
bell crank, 151
lever, 150
rack-type, 49
screw-type, 43
sector-type, 52–57
three-link, 153
two-cam computing, 60
types, 43

Nonlinear four-bar linkage, 161

Offset-pin, 83
component solver, 82–84
Optical tube, 349
Own ship component solver, 331

Parallactic angle, 342
Parallax corrector, 302
Projectiles, ahead-thrown, 406

Rack-type multiplier, 49
multiplying position values, 51
Range
effect of target motion on, 317–319
increments of, 321
Range components, 226
Range integrator, 320
Range prediction, 227
solving, 240
Range predictor, 239
Range rate
integrator, 322
obtaining, 320
Range recorder, 411
Range scale(s)
external, 360
internal, 360
reading on rangefinders, 359
Range table, 28–29
calculator, 34
use, 27
Range wind, effect of, 208
Range-wind correction, computing, 209
Rangefinder(s), 341–345
adjustments of, 351–354
care of, 370
checking, 355
construction of, 350
end reflectors, height adjustment, 353
internal adjustment, 356
inter-pupillary distance, 352
optics, 357
scales on, 359
spotting with, 369
stereoscopic, 349
values of unit of error, 363
Rangefinder formula for unit of error, 362
Rangefinder, reticule, 369
Rangefinder tube, optical elements in, 344
Rangekeeper operator correcting range, 317
Rangekeeper tracking section, 332
Ranging marks, 346
Rate control, 335
definition, 336
Rate-of-turn gyroscope, precession of, 131
Reference plane, 308
Reference point, 309
Reflectors, height adjustment, 353
Relative motion, 219–226
Relative-motion picture, 430
Relative target bearing
correcting, 330
generated, 328
observed, 328
Resolving a vector, 63
Reticules, rangefinder, 369–370
Rocket launcher(s), 412–414
stabilized, 415

Screw-drive speed input, 79
Screw-type component solver, 78, 79
adjusting, 82
Screw-type multiplier, 43
illustration, 44
multiplying negative values, 48
multiplying position values, 46
zero position, 45
Screw-type multiplier theory, 44–49
Sector-type multiplier, 52–57
multiplying with, 55
zero positions of, 54

Digitized by Google

Servo follow-up
control, 176
schematic, 176
unit, 177
Servo motors, 173
Shaft assembly, 140
Shell, finding range of, 25
Shell trajectories in a vacuum, 21
Ship components, solving, 68–70
Sight angle
computing, 241
corrections to, 393
solving for, 243
Sight deflection, 242
computing, 241
effect of cross level with, 284
Single-cam computing multiplier, 58
Single-cam multiplier, zero position, 59
Slide-bar assembly, 144
Sonar equipment, 426
Sonar range recorder, 427, 434
Spread gyro angle, 395
Stable vertical, 251
follow-up control assembly, 259
schematic diagram, 258
Standard ship organization, 5
Steam-driven torpedoes, 378
Stereo trainer, 371
Stereoscopic rangefinder, 344, 349, 351
range measurement, 360
Stern-dropped attack problem, 418, 422
Surface-air attack, 405
Surface fire control symbols, 449–452
Synchro follow-up(s), 184
single speed, 188–189
two speed, 191
Synchro transmission, 310
Synchro transmitting systems
course control, 190
fine control, 190

Target acceleration bug, 433
Target angle, correcting, 330
Target component solver, 331
Target deflection predictor, 241
Target motion, 221
components of, 222
solving, 222
Target, moving, sight angle for, 228
Three-link multipliers, 153
Time motor, 321
Torpedo(s), 376
afterbody, 376
battery compartment, 376
construction, 387
course, basic, 394
depth mechanism, 380
electric, 387
sections, 376, 377
steam-driven, 378
steering mechanism, 381
tail, 376
war head, cut-away view, 378
Torpedo director, 389
schematic, 400
Torpedo fire control, 389
instruments, 375
Train correction, 282
Train receiver, 303
Triangulation, measuring distance by, 341
Trigonometric functions of an angle, 453
Trunnion tilt
correction, 252, 277
deflection present, 285
no deflection present, 281
sight deflection present, 283
effect of, 276
effect of level on, 285
illustration, 288
Trunnion tilt errors, 275
no deflection, 278–280
train correction, 311
Tube indexing diagram, 386
Tube offset, use of, 399
Turret officer, 14
Two-cam computing multiplier, 60

Underwater attack problem, 415
Underwater fire control, 405
Underwater fire control system, 426–433
Unit of error
definition, 361
formula for finding, 362

Vacuum trajectory, 22
Vector(s)
definition, 390
resolution of by trigonometry, 65
resolving, 108
Vector gear, position of, 66
Vector input, 105

Digitized by Google

Vector solver(s), 63, 85–89
  adjustment, 88
  composition, 87
  strengthening the outputs, 88
Vector-solver outputs, strengthening, 88
Vertical parallax, 265, 307

Weapons, 427
  for ahead-thrown attacks, 411
Wind
  ballistic, 200
Wind—Continued
  caused by own ship motion, 236
  cross, 201
Wind computer, 214
Wind correction
  angles used to compute, 210
  computing, 215
  solving, 199
Wind-deflection multiplier, 241
Wind vector, 213
  resolving, 213

☆ U. S. GOVERNMENT PRINTING OFFICE: 1958 O—477058

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

YB 74433

Digitized by Google

Digitized by Google

YB 74433

Digitized by Google

Digitized by Google